MASARYK UNIVERSITY
Faculty of Economics and Administration

Field of study: Public Economics

EFFICIENCY EVALUATION IN THE MUNICIPAL SOLID WASTE MANAGEMENT

(HODNOCENÍ EFEKTIVNOSTI V ODPADOVÉM HOSPODÁŘSTVÍ OBCÍ)

Dissertation

Dissertation supervisor:
doc. Mgr. Ing. Martin DLOUHÝ, Dr., MSc.

Author:
Ing. Michal STRUK

Brno, 2018

Author's name and surname: Ing. Michal Struk

Dissertation title: Efficiency evaluation in the municipal solid waste management

Department: Public Economics

Dissertation supervisor: doc. Mgr. Ing. Martin Dlouhý, Dr., MSc.

Year of defense: 2018

Abstract

The aim of the submitted thesis "*Efficiency evaluation in the municipal solid waste management*" is to suggest ways for improving municipal solid waste management in South Moravian Region based on a detailed analysis of selected relevant efficiency factors. Chosen efficiency factors were identified both using available literature and quantitative analysis of collected data. Data were collected from more than 500 municipalities in South Moravian Region in the Czech Republic and subsequently used in a two-stage Data Envelopment Analysis in order to identify specific efficiency factors. Selected efficiency factors (convenience of waste separation, presence of incentives, effects of age structure and impact of competition among waste management providers) were examined in more detail and suggestions how these findings can be utilized in municipal waste management practice are provided.

Abstrakt

Předložená práce "*Hodnocení efektivnosti v odpadovém hospodářství obcí*" se zaměřuje na identifikaci a přezkoumání faktorů efektivnosti ovlivňujících odpadové hospodářství obcí v Jihomoravském kraji za účelem poskytnutí návrhu k jeho vylepšení. Zkoumané faktory efektivnosti byly vybrány na základě studia příslušné domácí a zahraniční literatury a kvantitativní analýzy primárních a sekundárních dat sesbíraných pro více než 500 obcí v Jihomoravském kraji v České republice s využitím dvoustupňové analýzy obalu dat. Vybrané faktory efektivnosti (vnímané pohodlí při třídění odpadu, existence pobídek, efekt věkové struktury obyvatel a dopad konkurence mezi odpadářskými společnostmi) byly podrobně prozkoumány. Výsledkem je soubor zjištění a doporučení pro možné využití získaných poznatků v praxi za účelem dalšího zvyšování efektivnosti v odpadovém hospodářství obcí.

Keywords

Municipal waste management, efficiency, DEA, waste separation, age structure, competition

Klíčová slova

Odpadové hospodářství obcí, efektivnost, DEA, třídění odpadu, věková struktura, konkurence

Declaration

I hereby declare that the dissertation "*Efficiency evaluation in the municipal solid waste management*" is my own work carried out under the supervision of doc. Mgr. Ing. Martin Dlouhý, Dr., MSc., and I have duly acknowledged all sources in accordance with the law, the internal regulations of Masaryk University, and the binding internal documents of Masaryk University and of the Faculty of Economics and Administration.

In Brno, May 2018

Author's signature

Acknowledgements

I would like to express my gratitude to Martin Dlouhý, Jana Soukopová, Jiří Hřebíček and Šimon Struk for lot of various help during writing this dissertation, numerous municipal representatives for providing me with the data, and my family for the patience and tolerance (mostly), especially my wife Janka.

CONTENT

INTRODUCTION **9**

1 EFFICIENCY AND MUNICIPAL WASTE MANAGEMENT **13**

1.1 DEFINITION OF EFFICIENCY 14
1.2 EFFICIENCY AND THE PUBLIC SECTOR 18
1.3 METHODS OF EFFICIENCY MEASUREMENT 23
1.4 WASTE MANAGEMENT 27
1.4.1 WASTE MANAGEMENT IN THE ENVIRONMENTAL PROTECTION 28
1.4.2 WASTE MANAGEMENT IN THE CZECH REPUBLIC 31
1.4.3 WASTE MANAGEMENT IN THE CZECH MUNICIPALITIES 33
1.5 EFFICIENCY IN THE MUNICIPAL WASTE MANAGEMENT – LITERATURE OVERVIEW 43
1.5.1 IDENTIFIED FACTORS OF EFFICIENCY 52

2 MUNICIPAL SOLID WASTE MANAGEMENT IN THE SOUTH MORAVIAN REGION **55**

2.1 SOUTH MORAVIAN REGION IN THE CZECH REPUBLIC 55
2.2 BACKGROUND OF THE DATA COLLECTION 56
2.3 DATA COLLECTION PROCESS 62
2.4 DATA DESCRIPTION 76
2.5 QUALITATIVE FINDINGS 80

3 EFFICIENCY EVALUATION IN THE MUNICIPAL SOLID WASTE MANAGEMENT **87**

3.1 SAMPLE DESCRIPTION 87
3.2 DATA ENVELOPMENT ANALYSIS 89
3.3 DEA EVALUATION OF EFFICIENCY 98
3.3.1 IDENTIFIED FACTORS OF EFFICIENCY 103
3.4 DISCUSSION OF THE FINDINGS AND LIMITATIONS 103

4 EFFICIENCY FACTORS IN THE SOUTH MORAVIAN MUNICIPAL SOLID WASTE MANAGEMENT **111**

4.1 INCENTIVES, DISTANCE AND KERBSIDE COLLECTION 111
4.2 AGE STRUCTURE 128
4.3 COMPETITION AND PUBLIC VS. PRIVATE NATURE OF THE WASTE MANAGEMENT PROVIDER 148
4.4 DISCUSSION OF THE FINDINGS AND SUGGESTIONS FOR PRACTICAL APPLICATIONS 158

CONCLUSIONS **163**

LITERATURE **167**

SUMMARY, LIST OF FIGURES, TABLES AND ABBREVIATIONS **189**

INTRODUCTION

Waste management is today commonly perceived as a service provided by the public sector. More specifically it is considered as one of the standard services provided by the municipalities. Arguments for providing municipal waste management as a public service derive from the nature of the service itself and the related private sector failures. This is understandable, as waste generation creates externalities that impose costs also on the subjects different from those that generate the waste. Public provision of services dealing with issues when the producer of the externalities does not bear the costs is then a natural consequence.

But while on the one hand public provision of some goods or services can, to a certain point, correct the market failures it was intended for, on the other hand it can, and often does create other problems known as public sector failures. One of them is the question of the efficiency of public expenditure. Unlike in private sector, where companies primarily aim for profit generation, thus the question of pursuing efficiency is naturally incorporated in their decisions, in public sector the main goal is the benefit of the society, with efficiency being less of an important factor in decision making. The conflict then becomes clear with efficiency on one side and benefits to the society on the other.

In this thesis I focus specifically on municipal waste management, which is in developed countries commonly accepted as a public service and provided accordingly by the public entities, whether directly by them or by contracting external providers. I do not question whether the provision of waste management as a public service is meaningful, that is to be decided elsewhere. My goal in this thesis is to examine the ways how municipal waste management can be improved (both from the supply and demand side) and I do it primarily from the economic perspective, however, with some overlaps to the environmental perspective as well. My objectives in this thesis are therefore to

1) describe situation in municipal solid waste management in a selected Czech region;
2) identify relevant efficiency factors in this region using both collected data and available literature, and based on further analysis provide policy suggestions for improving municipal waste management in the region.

In the first chapter I provide foundations for the term efficiency, concentrate on the efficiency in the public sector, and describe common ways how to measure efficiency. Then, after the definition of the key concepts that this thesis is based on, I provide an introduction to the municipal waste management in the Czech Republic, as it represents the focus are of the thesis and it is necessary in order to orientate better in the examined area. After that I provide an overview of the studies relevant to the issue of efficiency of waste management, from which I identify efficiency factors that literature usually lists as important with respect to municipal waste management. Deduction method was then used for creating the assumptions about the role of the selected factor, of which some are then more thoroughly examined in the fourth chapter in order verify the assumptions.

In the second chapter I describe the data that I used in this thesis and the data collection process together with some initial findings that emerged already during the data collection part of my research. The reason why this amount of space is devoted to this part is because in order to examine the issue of efficiency of municipal waste management the data had to be collected directly at the municipal level for this specific purpose. The data collection thus represents a significant part of the research itself. Method of analysis of the original collected data was used in order to identify important factors that influence MSWM from the perspective of municipal representatives.

In the third chapter I employ the collected data in an empirical analysis using Data Envelopment Analysis together with the secondary data from public databases and based on induction identify the potential factors that could play an important role in the municipal waste management. As the primary data was collected only from selected region (even though vast majority of municipalities participated), the validity of the findings has its limitation regarding the whole Czech Republic. Nevertheless, the sheer size of the sample and the relative homogeneity of Czech municipalities make it possible to generalize the findings to a certain extent.

In the final fourth chapter I examine more thoroughly selected factors that emerged in the previous efficiency evaluation. In separate subchapters I examine effects of incentives,

distance, kerbside type of waste collection, age structure of the municipal population, competition presence and ownership nature of the waste management service provider. Method of verification of the assumption regarding the role of selected factors was used by employing relevant statistical methods.

Finally, based on the results I conclude the findings of my thesis and discuss the potential of incorporating these findings in municipal waste management design and suggest ways how to improve the current practices in the area of municipal waste management.

1 EFFICIENCY AND MUNICIPAL WASTE MANAGEMENT

"***Efficient*** *– productive of desired effects; productive without waste*"

*"**Efficiency** – the quality or degree of being efficient"*

(Merriam-Webster Online Dictionary)

Pursuing efficiency is a permanent process in both public and private sector. Considering the *homo economicus* concept, efficiency is something that is naturally connected with rational decision making. Thus the efficiency is something we all are doing simply by nature without necessarily thinking about it. It is generally accepted that, when given several options, one chooses the option that, in his own perspective, provides him with most of an output while consuming the least of an input. Aim of this chapter is to further explore the concept of efficiency and link it to the waste management that is examined further in this thesis.

When considering individual decision making, the problem of efficiency might be seen as a much more simple – if assuming that we make rational decisions, it implies that these decisions are also efficient. Of course we run to the problem of what rationality is and the question whether one makes rational decisions. But this raises another issue – who decides what is rational and what is not? The issue with the rationality is in the fact that when considering individual rationality, it is relatively easy to define it. People make choices willingly, and if they choose an option, it is the option that, based on their current knowledge and ability to evaluate given options that are able to fulfill their desires in an accepted way, was the best out of the given range. The other thing is how this choice might turn out later, but this does not contradict with the fact that initially people made a subjectively rational and efficient decision.

In the case of collective decision making the problem of rationality becomes trickier. The question here is who should decide what is rational and what is not. Although there is a philosophical concept of objective rationality that can be hypothetically worked with, defending such concept without setting many additional conditions and further restrictions becomes next to impossible. Nevertheless, in reality there exists something like this "*quasi-*

objective" rationality in decision making, represented, for instance, by transferring the decision making to the deputy elected in the voting process. The outcomes of such decision making, however, depend in the end on the personal qualities of the deputy himself.

Although a simple word, there still is no consensus in what the term *efficiency* exactly means. The issue is that it has different meanings depending on the context, although every time the definitions follow the same idea. In the first subchapter general aspects of the efficiency are provided in order to define how it should be understood in this thesis. In the second subchapter I sketch out the relationship between efficiency and the public sector, together with the specifics related to the public sector. In the third subchapter I provide the basic overview of the methods commonly used for efficiency evaluation (including the role of econometrics as an important tool that can significantly improve the primary results of efficiency analyses). In the next part I provide the overview of the waste management and its relation to environmental protection and then focus more specifically on the basics of waste management in the Czech Republic and its municipalities. Finally, in the last subchapter I provide an overview of the important efficiency studies performed in the area of MSWM and some concluding findings of these studies.

1.1 Definition of efficiency

At this point I provide several definitions of the term *efficiency*, explain how it is understood in the rest of the thesis and point out the specific aspects of efficiency when concerning quantitative analysis. Very simple definition of efficiency can be "*the absence of wastage*" (Vlček, 1992:27). However, this definition is, in my opinion, more philosophical than practical (although it is correct) and makes it difficult to define a way of evaluating whether some unit is efficient or not, or alternatively how efficient the unit is when compared with other evaluated units.[1] Much more quantifiable definition of efficiency offers for example Ochrana (2005:164), who defines efficiency as the maximization of ratio between outputs and inputs (presumably costs). This definition basically says that a unit is efficient if it is able to

[1] Here I would like to stress the part "*compared to other evaluated units*". In my opinion one cannot state that something is efficient solely by itself. Efficiency evaluation has to include a set of at least two units in which these units can be compared together with the result of one unit being at least as efficient that the other. Without other units for evaluation, or at least some benchmark, it would be like competition with just one contestant – this contestant would always finish both first and last.

produce more from consuming less than other units it is compared with. The concept behind this goes back to the Pareto efficiency, which is in the words of Musgrave (1984:295) described as "*economists consider an arrangement efficient if resources are used in a way which does not leave a possibility of alternative arrangements under which somebody could be better off without anyone being worse off.*"[2]

However, in practice it is often impossible to know whether there is no other possible arrangement of resources that could provide a better result. Therefore it is for our purposes probably the most practical to define efficiency as a ratio between a set of outputs of a transformation process and a set of inputs used in this transformation process (Jablonský, Dlouhý, 2004:12). Such definition of efficiency automatically adds the assumption that there is some level of wastage by the decision making unit, which in my opinion seems as an appropriate real world assumption. Efficiency of a unit then can be understood as a rate of this unit's performance with respect to an ideal 100% efficient unit. And finally one more philosophical definition, according to which is the efficiency of spent resources considered as the pursuing of the given goals set as the basic criterion of rationality, and it is in the very center of evaluating the organizational process of the pursued policy. Acquiring the state of economic efficiency then means the situation where the choices between the goals and the alternative ways of achieving them are made in the way that the maximal total benefit from the available resources is achieved (Malý *In* Strecková, 2005:7).

After defining efficiency as a certain measurement of unit's performance, we logically encounter the issue of how to measure this efficiency. This is still an unsolved problem not just in the public sector. There are numerous methods of how to measure efficiency. Medveď, Nemec, Orviská and Zimková (2005), or Ochrana (2001, 2011) provide an overview of this issue with respect to the 3E (economy, efficiency, effectiveness) concept in the public sector. Commonly used evaluation methods are for example single criterion methods (also known as input-output methods) consisting of CMA (Cost-Minimization Analysis), CBA (Cost-Benefit Analysis), CEA (Cost-Effectiveness Analysis) and CUA (Cost-Utility Analysis), various

[2] This concept of considering efficiency is usually called "*allocative efficiency*". However, it assumes that one is able to compare all available arrangements of resources. In my opinion this concept works well in theory, but the complex situations in real life might make it impossible to even consider all possible arrangements, not speaking about their further evaluation and comparison.

multicriterial methods or financial methods like FV (Future Value), NPV (Net Present Value), ROI (Return of Investment), PM (Payback Method) and IRR (Internal Rate of Return). Listed methods provide relatively easy way of comparing evaluated units, but on the other hand are quite limited when it comes to more complex decision making problems that include multiple inputs and outputs. More advanced methods for efficiency evaluation can be found in the field of operation research, for example in Jablonský (2002).[3] The fact is, however, that each of these methods has its pros and cons, and none of them is perfect. Thus, each time some of these methods are used, the related limitations of the method should be kept in mind. Mintzberg (1996) calls it "*the myth of measurement*", noting that "*many activities are in the public sector precisely because of measurement problems. If everything was so crystal clear and every benefit so easily attributable, those activities would have been in the private sector long ago*". And besides that, the most efficient unit does not have to be the "*best*" unit, unless we define best strictly as the most efficient. Also there is a difference between outputs and the outcome. A unit can perform very well in certain output indicators (and thus be considered most efficient) but still be outperformed, for example, by overall or combined result of other units. All this depends on how is efficiency defined, as well as the selection of method for the efficiency evaluation.

But let us move further with a more specific type of efficiency that is the main concern of this thesis – economic efficiency, and to be even more specific technical efficiency. The relationship between the two is simple, as economic efficiency consists of technical and allocative components. The technical component refers to the ability of avoiding waste, either by producing as much output as technology and input usage allow, or by using as little inputs as required by technology and output production. Thus, the analysis of technical efficiency can have an output-augmenting orientation or an input-conserving orientation. Allocative component refers to the ability of combining inputs and/or outputs in an optimal proportion in light of prevailing prices. Optimal proportions then satisfy the first-order conditions for optimization problem assigned to the production unit (Fried et al., 2008:20).

[3] For example Lovell (2002:23) provides a brief discussion of the use of these "*techniques*" in the public sector with listing their pros and cons.

For the clarification I stress here that in the further text I use the terms efficiency generally to refer to the technical efficiency and I leave out the discussion about allocative efficiency, which requires the presence of price information. Just one more note on allocative efficiency – it corresponds to the ratio of cost efficiency and technical efficiency (Porcelli, 2009). Nevertheless, the costs aspects of MSWM will be included in the practical part of the analysis.

Probably one of the first definitions of technical efficiency was provided by Koopmans (1951), who explained it in a bit of Pareto style as "*a producer is technically efficient if an increase in output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output*". Some refer to this as "*Pareto-Koopmans*" condition for technical efficiency (Ray, 2004:2). Koopmans had here already recognized the potential of linear programming for economic analysis and optimization, which was developed later.

Around the same time Debreu (1951) started to define what has later, after merging with Farrell (1957) became known as Debreu-Farrell measure of technical efficiency. With an input-conserving orientation it is defined as: *"(one minus) the maximum equiproportionate reduction that is feasible with given technology and outputs*" (Fried et al., 2008:20). Or in other words as a "*...(radial) reduction in all inputs that still allows the production of given outputs, a value of one indicates technical efficiency and a score less than unity indicates the severity of technical inefficiency*" (Porcelli, 2009). Or alternatively, any deviation of this measure from one was interpreted as "*a deadweight loss suffered by society due to inefficient utilization of resources*" (Ray, 2004:3). In case of an output-augmenting orientation, the Debreu-Farrell measure is defined as the maximum radial expansion in all outputs that is feasible with given technology and inputs. In both orientations, a value of unity (1) indicates technical efficiency because no radial adjustment is feasible, and a value different from unity (less than 1) indicates the severity of technical inefficiency (Fried et al., 2008:20).

Although Debreu-Farrell measure might seem at first a bit difficult to understand, it creates the foundations of how the efficiency is being understood when acquiring results of more

complex efficiency measuring techniques such as later presented DEA, where efficient units acquire value of one (unity), while inefficient units acquire lower values, depending on the level of their inefficiency.

Already mentioned Farrell (1957) made his breakthrough contribution in the topic of efficiency by constructing a linear programming model using the actual input-output data of a sample of firms with the result of a numerical measure of technical efficiency of individual firms in the sample. Farrell recognized that a function fitted by the standard OLS regression could not serve as a production frontier, as the analyzed points would lie on both sides of the fitted line. Such line obviously would not represent an efficient frontier, but rather an average one. Therefore Farrell approximated the underlying production possibility set by the convex hull of a cone containing examined input-output bundles (Ray, 2004:3). Nevertheless, it took many years before further progress in this area was made, and, as some say, Farrell's contribution to the area of efficiency measuring was ignored for more than two decades (Russell, 1998).

1.2 Efficiency and the public sector

When speaking about efficiency in the public sector, a good starting point is to explain the differences between the efficiency in public and private sector. Private sector, when it comes to efficiency, offers one very elegant shortcut through the institute of prices (carrying exhausting amount of information, however trivial and clear the price solely by itself might appear). In private sector pretty much everything has its price, everything is monetized. Thus one has the option of reducing efficiency measuring to the examination of the firms' profit, even though it is in fact a very strong simplification. On the other hand, in public sector the decision maker often faces outputs that are not expressed in financial means (the reasons for that being for example political, moral or due to the absence of a market equivalent). This means that in case of efficiency evaluation in the public sector we do not face just one problem of specifying what efficiency is, but also the problem of assessing the effects or the outcomes that are produced in the public sector. Even such simple comparison then reveals that the two sectors are very often not interchangeable.

The objectives pursued by the public and private organizations are different, as the private sector aims for profit, while the public sector seeks not only to obtain economic benefits, but also to obtain social benefits, with the stated primary objective to ensure the public welfare (however, profit maximization might still be the secondary goal). The goals of the public sector are generally driven by the political decisions and the political decisions are driven by the political representatives elected by the people. And the people usually elect those representatives who seem to be the most capable or suitable to fulfill their needs and desires. The trick is, however, in the fact that these needs and desires have often intangible form, and as such they cannot be easily expressed directly in the form of money or not even in any tangible form at all. Among these desires are, for instance justice, equality, safe environment, freedom, productive life, etc. And how does one express such things in the monetary form? This is also the reason why private sector in general is not interested here, as, although it might be simple to express the costs, it is next impossible to evaluate the outcomes in terms of money. Or one can try, but any results would be immediately subdued to a wide criticism, as these thing have very broad range of values in the perspective of individual people.

Also there is a problem that in the public sector in many cases the direct and immediate economic benefit is missing. For example, if a school is built in a village, the effort involved in this investment can be easily identified as all the costs incurred for the construction, the material basis, the wages, etc. But how can we measure the benefits in this case? We can identify the social benefits, such as increasing literacy, ensuring better labor market, higher living conditions, etc. But how should we express these benefits in the form of money? Or another example – when building a highway by the public sector we should not look only at the direct benefits, but also consider indirect ones besides collection of highway taxes (if applied at all), like for instance reduction of the road accidents, reduction of the traveling time, improved conditions for the economic development of the region, etc. If taking into account only the directly expressed monetary benefits, the calculated efficiency would be much lower than the real one, possibly resulting in no investment and development at all.

The private sector thus rather seeks primarily economic benefits, while showing a reduced concern for the social and environmental issues, even though nowadays many companies are starting to improve the mentality and trying to place the social responsibility vision with the

one of obtaining profit. This aspect of public sector (taking into account more than just direct financial aspects) should be kept in mind when planning any efficiency evaluation. For a better understanding of the key differences between public and private organizations I provide the following Table 1.

Table 1: Main differences between public and private organizations

Public organizations	Private organizations
Are usually monopolies	Operate on competitive markets
Serve the citizens	Maximize the investment's profit
Are driven directly or indirectly by the politicians, who should reflect the interests of the citizens	Leaders of companies are responsible to the shareholders, to the boards; they seek profit maximization
State organizations are more rigid due to the process of decision making and implementation	Are more flexible, easier to manage because the decision is taken by a single leader
Distribute, redistribute and regulate resources	Produce and distribute resources
Are sometimes poorly funded	Are financed under based on their productivity or if the investment decision is feasible
Citizens are often poorly informed and suspicious of the government	Investors and shareholders are well informed and the ongoing activities of the company and the market evolve

Source: Mihaiu et al. (2010)

Next important thing to keep in mind when dealing with the efficiency in the public sector is the 3E concept, where Es stand for economy, efficiency[4] and effectiveness, or alternatively the overall performance (Nemec et al., 2010:52). This concept is sometimes referred to as Value for Money (VFM) and is among the most important concepts in the field of public finance. To put it in very simple terms it stands for economy, efficiency and effectiveness means to achieve the desired goals. A common mistake in practice is to confuse effectiveness with efficiency which are different concepts but work complementary in the 3E's approach. Table 2 provides basic overview of 3E criteria. Let us look at each of the Es in more detail.

Table 2: Overview of 3E criteria

Criterion	Means of monitoring	Best quality
Economy	Cost minimization	Ideally the lowest price
Efficiency	Costs per unit of outcome	Lowest cost per outcome unit ratio
Effectiveness	Rate of fulfillment	Highest rate of objective fulfillment considering costs

Source: Ochrana (2006:52)

[4] Important note here is that the term efficiency in the 3E concept and the efficiency as used in the rest of the thesis are not identical, although they share some common aspects. Outside of 3E concept, efficiency in this thesis refers to the technical efficiency, as described in the subchapter 2.1.

The first E, *Economy*, stands for minimizing the cost of resources ("*doing things at a low price*"). It covers the financial side on which an activity is achieved. The desired objectives and goals should be achieved with as little as possible use of the resources (Nemec et al., 2010:48). Because we live in a world in which economics permeates every aspect of our lives, it is fundamental to balance the use of resources in order to achieve the right goals with the reasonable cost. There is a difference between Efficiency and Economy, as the former states the volume of resources and the way of using them, while the latter looks primarily at the costs.

The second E, *Efficiency*, stands for performing tasks with reasonable effort ("*doing things the right way*"). Efficiency means the right use of resources in order to accomplish a task. It is understood as a "*wise*" consumption of inputs used in the transformation process towards the desired goals. It is important not just to attain the goals, but it is also fundamental to see how these goals can be reached with the least effort and/or resources. Therefore when choosing between comparable option, the most efficient is one that has the lowest costs per unit of output (Nemec et al., 2010:49). Improving efficiency thus means that the company is in a trend of reducing wastage and consuming less to deliver the same amount of value.

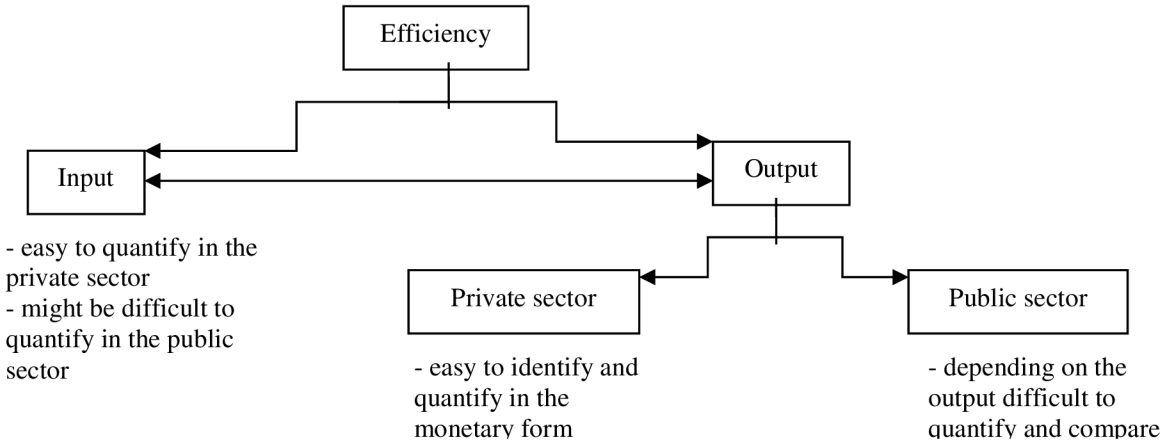
The third E, *Effectiveness*, stands for the extent to which objectives are met ("*doing the right things"*). Effectiveness should therefore be understood as the level at which the goals are being achieved, for instance on a scale of 0-100%. A successful performance in terms of effectiveness is then to fully meet the beforehand set quantitative indicators. Or alternatively, such usage of resources that the set goals and objectives are optimally met (Nemec et al., 2010:49).

Next important term to define, when dealing with the efficiency in the public sector, is public expenditure. Very simple definition might be, let us say "*the money that is somehow spent by the government*". In literature we can find for example a broad definition from Sivák et al. (2007:202), according to which "*the existence of public expenditure is related with the character and functions of the public sector and its relation with the private and non-profit sector. The goal of the public sector is to ensure the maximization of the welfare to the most*

people possible." And the most obvious "*tool*" for ensuring the maximization of the welfare to the people is "*to spend financial means in order to reach the welfare.*" In other words this says that public expenditures are public sector's means of ensuring the welfare to the people. Sivák et al. (2007:205) offers yet another definition in which "*public expenditure is financial expression of the government's interference*", and Hillman (2009:3) would probably add "*...in order to achieve its social objectives*" (or in other words "*that, what is in principle expected to be sought by consensus*"). However, here we encounter the philosophical question of what is good or what are the legitimate objectives of the government, as well as the definition of public interest and whether we truly are able to compare between the various alternatives. But trying to solve such questions is far beyond the goal of this thesis. Let us just assume that we are able to compare various goals and find consensus on which of them is "*best*" and that we are also able to agree whether something is or is not a public interest.

When considering the determination of the specific efficiency indicator that we are planning to use for the efficiency evaluation in the public sector, we can follow the scheme in Figure 1. I assume here that the efficiency is provided by the relationship between the effects, or the outputs, and the efforts or the inputs. The relationship is apparently simple, but practice often proves the contrary, because identifying and measuring inputs and outputs in the public sector can often become a difficult operation. Following scheme shows the main differences when making efficiency evaluation in the public and private sector.

Figure 1: Scheme of determining the specific efficiency indicator



Source: Mihaiu et al. (2010)

Based on the provided scheme, the direct factors of influence on the efficiency are:

1) The inputs. In the public sector the resources are sometimes harder to quantify than in the private sector, because public services often overlap and resources from several sources are used. But, in general, the inputs are given by the costs incurred for the project/service in matter.

2) The outputs. In the public sector these are usually much more difficult to quantify than in the private sector, because they often have both economic and social dimension. In the private sector the outputs have typically market value and thus are from the private sector decision maker perspective easily evaluated. On the other hand, in the public sector is this process often much more cumbersome. To evaluate the outputs from the public sector we must carefully define the indicators that will be evaluated, and through which a level of efficiency will be determined. Such process might often get complicated and also kind of vague in some areas.

1.3 Methods of efficiency measurement

There are multiple methods that can be used for measuring efficiency. One can choose from the very simple ones to the relatively complex ones. The choice should depend both on the importance of the result and the ability of the evaluator to fully utilize the specific method, including the ability to provide sufficient and relevant data for the evaluation. Following subchapter describes three basic categories of such methods. But one should also remember that further analysis is often necessary, in order to find also reasons that make analyzed unit inefficient and how this can be improved (Jablonský, Dlouhý, 2015:7).

Single criterion methods

Very common are single criterion efficiency measurement methods that use a calculated ratio between the inputs and the outputs. Probably the most known method in this category is Cost-effectiveness Analysis, or CEA. This method is used for calculating ratios of a certain output (typically a physical unit) and the related costs used in the transformation process when comparing several alternatives. Necessary with this method is to have comparable outputs from the evaluated alternatives. Advantage of this method is in the fact that outputs can be

used in the evaluation process in their natural form, without the need for any additional adjustments. The result is then presented typically in the form of costs per unit produced, or alternatively units produced per certain amount of costs. On the other hand, CEA does not tell anything about whether it is worth to spend the resources in order to obtain the outputs. But this should not be seen as a flaw of the method, as the goal of the CEA is to compare the alternatives and not to assess the reasonability of producing certain output. This should be decided either politically or by using other relevant methods. Another evaluation method, Cost-utility Analysis, or CUA, can be used in cases with somewhat more complex outputs – for instance in healthcare, when using quality adjusted life years provided by some kind of treatment instead of just additional life years that would be used in the CEA. Both of these methods can be well used in less complex decision making problems where we are able to abstract from additional conditions and characteristics of evaluated units, as these methods are able to cover only very few factors that might have the influence on the overall efficiency of the production unit (Jablonský, 2004).

Multicriterial methods

In cases of more complex measurement of efficiency one can use multicriterial evaluation methods based on the aggregation of inputs and outputs. These methods share the ability to incorporate multiple inputs and outputs and then calculate a ratio of this sum of inputs and the sum of outputs. Important is, however, to assign the appropriate weights in order to obtain a relevant numerator (weighted sum of outputs) and denominator (weighted sum of inputs) in the calculation. When compared to the CEA, the obvious advantage is the ability to include larger amount of evaluated unit's characteristics in the evaluation. However, there still remain issues with assigning the proper weights to the individual characteristics and the issue of comparing units of a notably different size.

Frontier analysis methods

For even more complex efficiency measurement one can use methods based on the construction of the production frontier from the set of evaluated units. Most important methods representing this field are Stochastic Frontier Analysis, or SFA and Data Envelopment Analysis, or DEA (explained in detail in subchapter 3.2). The origins of both

methods come from Farrell's (1957) study, with the difference being in certain aspects like the use of parametric approach instead of nonparametric. One can generally say that after Farrell's seminal study there have been two main paths of further research – one became later known as DEA while the second as SFA.

SFA represents an efficiency evaluation method based on econometric approach. It is a parametric method that considers the presence of a statistical noise, which is one of its main differences when comparing with DEA. As put by Greene (2008:93), it is *"essentially a regression model that is fit with the recognition of the theoretical constraint that all observations lie within the theoretical extreme"*. Measurement of efficiency is then the empirical estimation of the extent to which observed units achieve estimated frontier. The origins of SFA come from Farrell (1957), who suggested that one could usefully analyze technical efficiency in terms of realized deviations from an idealized frontier isoquant, which falls naturally into the econometric approach. The inefficiency is thus identified as the disturbances in the regression model (Greene, 2008:93). One of the discussants of Farrell's study, Sturrock (1957), then conceptualized the proposed production frontier as stochastic. He opposed that the output producible from an input bundle would be subject to chance variations beyond the control of the firm and argued against using 100% efficiency that is required in DEA (Ray, 2004:5). The pioneering works in this area came from Aigner and Chu (1968), who considered production frontier to have a Cobb-Douglas (log-linear) form with assigned random non-negative variable, let us say u, associated with technical inefficiency. There are various approaches for estimating u, for instance Aigner and Chu (1968) used linear programming, Afriat (1972) assumed u to have gamma random distribution and for estimation used method of maximum likelihood, while Richmond (1974) used a specific modified OLS technique. However the most notable work in this area came several years later by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) who both, just one month apart from each other, proposed the stochastic frontier model that is being applied by the researchers up till now. Third, although less known *"founding"* paper about SFA came from Battese and Corra (1977).

The initial model of SFA proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) has the form of

$$\ln q_i = x_i'\beta + v_i - u_i$$

where $x_i'\beta$ determines the shape of the production function, v_i stands for symmetrical random error to account for statistical noise (either positive or negative), and u_i is a random non-negative variable associated with the technical inefficiency. Together $v_i - u_i = \varepsilon_i$ or simply the error term. Such model is called stochastic frontier production function because the output values are bounded from above by the stochastic variable $\exp(x_i'\beta)$. The goal then is to minimize u_i subject to $u_i \geq 0$ (Coelli et al., 2005:242). The economic logic behind this specification is that the production process is subject to two economically distinguishable random disturbances – statistical noise represented by v_i and technical inefficiency represented by u_i. Errors v_i are assumed to have symmetrical distribution, component u_i is assumed to be distributed independently of v_i while being non-negative. These assumptions are rather strong ones (Mastromarco, 2008). Stochastic frontier models are estimated mainly by Modified Ordinary Least Squares (MOLS), or by maximizing the likelihood function directly. More about these methods and about the theory behind SFA can be found in Fried et al., (2008) or in more advanced Kumbhakar and Lovell (2000).

The main advantage of SFA is the presence of a disturbance term representing noise, measurement error, and exogenous shocks beyond the control of the evaluated unit. This is in clear contrast with DEA, where efficient units have to lie directly on the efficiency frontier created by the peers, and any deviation from this was considered as inefficiency. This allowance for statistical noise, together with nonparametric nature of SFA, is a very strong argument for SFA, if choosing between the two. Another feature of SFA is its attempt to determine the absolute economic efficiency against some imposed benchmark unlike DEA, which evaluates efficiency between the analyzed samples. And, as SFA is of statistical nature, it allows for statistical testing of hypotheses (Worthington, 2014). Further disadvantages related to the econometric/statistical nature of SFA are explained in Greene (2008).

Econometric evaluation of additional efficiency factors

Finally, econometric tools can be very well used in the efficiency measurement for analyzing the relevance of additional factors that can influence efficiency of the production units. In many cases we might have additional data about the production that we cannot simply utilize in the previously listed methods. These can include, for instance, presence of various qualitative characteristics. We can include such characteristics (after, for instance transformation into the dummy variables) in the subsequent regression analysis with the efficiency obtained from the previous analysis as the dependent variable, together with various other characteristics as the independent variables. Results of the regression can point us in the further direction of where to focus our research. Two-Stage DEA that is used later in this thesis represents one such method, where initial efficiency score is calculated using standard DEA and the obtained score is then used in the subsequent regression with the additional available data in order to identify factors that can have significant effect on the efficiency score of the evaluated units.

1.4 Waste management

In this thesis I focus specifically on the efficiency in the field of waste management, which is today commonly secured by the public sector as a public service. In this subchapter I provide an overview the waste management and specifically municipal waste in the Czech Republic primarily from the economic perspective. This provides reader with an idea of the importance of this field. The examination of efficiency and factors that influence municipal waste management which represent the primary focus of this thesis then naturally follows.

This subchapter firstly introduces the reader to the environmental protection in the Czech Republic from primarily expenditure perspective and then focus on the area of waste management, as it is the main field of research of this thesis. Then, in order to show how waste management is connected with the public sector and specifically municipalities I describe in detail what are municipal obligations in the waste management area, what actually this service means, and how it works in practice, including financing, expenditures, practical aspects, etc. Provided perspective will be primarily economic and not environmental.

Inclusion of this introduction is necessary in order to understand the importance of further search for ways how to improve municipal waste management.

1.4.1 Waste management in the environmental protection

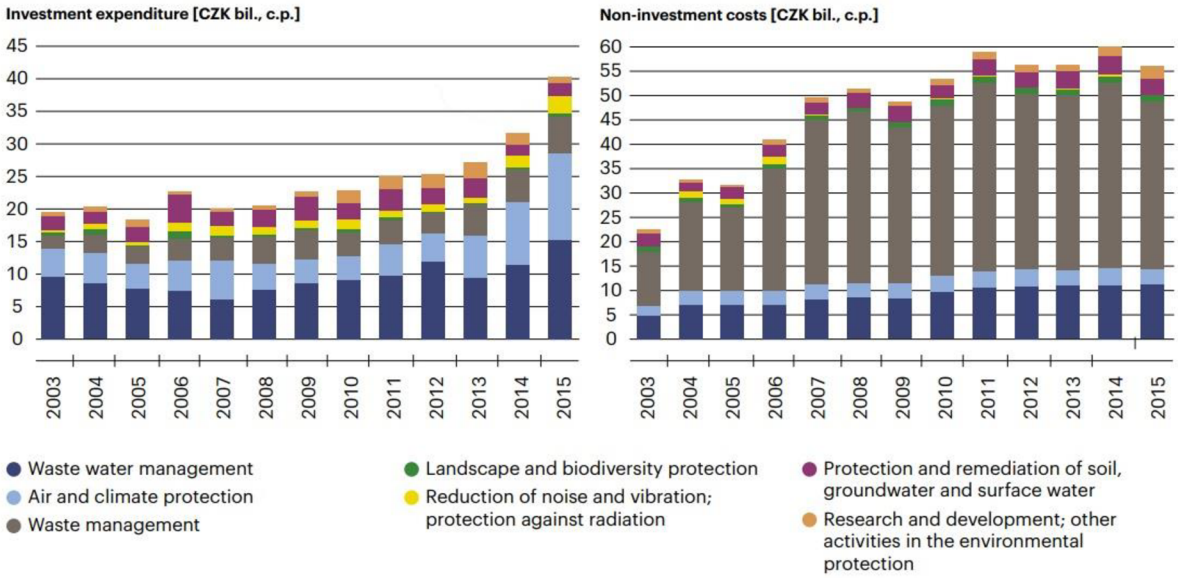
Waste management is part of a broader category of environmental protection. Environmental protection in general represents activities or practices of protecting natural environment on all kinds of levels from individual to global, and for the benefit of both individual people and environment as a whole.

Various aspects of environmental protection are studied extensively and, let us say that, there is a global consensus on the importance of it. The importance of environmental protection and related environmental policies started to emerge in 1970s as a result of the book *Limits to Growth* (Meadows et al., 1972). This book was the first widely noticed report that warned about the consequences of economic and population growth with a finite supply of resources. While there is a substantial body of both criticism and defense of the main message of the book, it definitely brought a worldwide attention to the issue of environmental protection. One of the consequences of the report is continually increasing role of environmental policies in all aspects and increasing pressure to keep in mind environmental aspects in all other kind of public policies, and primarily expressed in the focus of environmental policy itself.

One might ask why is environmental protection such an issue? The reason for that is the fact that the environment is basically the most important source of production factors for the economy, it defines the basic conditions for the production itself, and therefore it is in the very interest of whole society to avoid or at least limit the negative effects of production process and human behavior on it. The main problem here is the fact that individually rational human economic decisions have in the end often negative impact on the whole society. These issues have been known to the economic theory for a long time and include concepts of the tragedy of commons, prisoner's dilemma and negative externalities. However, it is not among the goal of this thesis to address these issues, but merely focus on a selected part of the environmental protection area and help to improve it.

One way how to examine the focus of environmental policy is through the focus of the environmental protection expenditures, or EPE. The areas of protection where expenditures flow are thus the demonstration of the policy priorities – important issues are those that get financed. Let us look at the development of EPE in the Czech Republic in last years that show specific areas of environmental policy focus.

Figure 2: Capital (investment) and current (non-investment) EPE in the Czech Republic, 2003-2015



Source: MŽP (2017a:5)

Figure 2 shows the development of EPE since 2003. There are two parts of the figure – capital (investment) and current (non-investment) expenditure. The difference between them can be demonstrated with the differentiation in the type of activity they are used for. Capital expenditure is used usually for purchasing fixed assets or an infrastructure that is projected to last for a longer period (typically multiple years), and usually without knowing exactly when the assets will need to be renewed. This is also the reason why such expenditure does not occur regularly, but more likely in times when there is either a need for such an investment or there are available funds for financing it. On the other hand, current expenditure happen regularly and much more often, as they are used typically for covering repetitive activities and are more likely to cover services instead of purchasing fixed assets with long term lifespan.

The difference between these two categories also explains the different structure of the expenditure. For example let us look at the largest expenditure categories from both parts of the Figure 2, wastewater management in capital expenditure and waste management in current expenditure. In case of wastewater management the majority of expenditure is used for infrastructure like sewage system and water treatment plants and slowly covering more and more municipalities in the Czech Republic. Once this infrastructure is operating, regular expenditure is usually relatively low, as this is a kind of infrastructure is designed to last for decades. However, initial investments are usually very high and in many municipalities can represent amount comparable to several years' total municipal budget. Nevertheless, there are usually ways how to co-finance such projects from national or international sources and thus somehow reducing the pressure on municipal budgets. On the other hand, waste management represents a different kind of activities with different structure of expenditures. Majority of waste treatment facilities are privately owned and private companies offer waste management services to the public entities. As waste is practically a product of almost any kind of consumptions and people need to consume in order to survive, the result is a continuous stream of waste that needs to be taken care of, requiring regular waste-related services.

In Figure 2 we can see that in the category of capital expenditure major areas are wastewater management and air and climate protection. In practice, wastewater areas usually cover infrastructure for water management and treatment, like improving existing or in some cases even constructing whole sewage system together with corresponding water treatment facilities. In case of air and climate protection, majority of finance flow to the measures of reducing emissions of hazardous material into the air, and can cover mostly improvements of certain transport corridors and reduction of impacts of stationary pollution sources (like heating plants or incinerators).

In the category of current expenditure, the major area is waste management. As was mentioned above, this is a consequence of the nature of the waste generation producing a continuous stream of waste that has to be taken care of. While there might be some measures that could in certain aspects reduce the amount of generated waste or somehow improve the existing waste streams, the basic need of waste collection, transport and treatment remains largely the same, and requires repetitive care and thus repetitive expenditures as well.

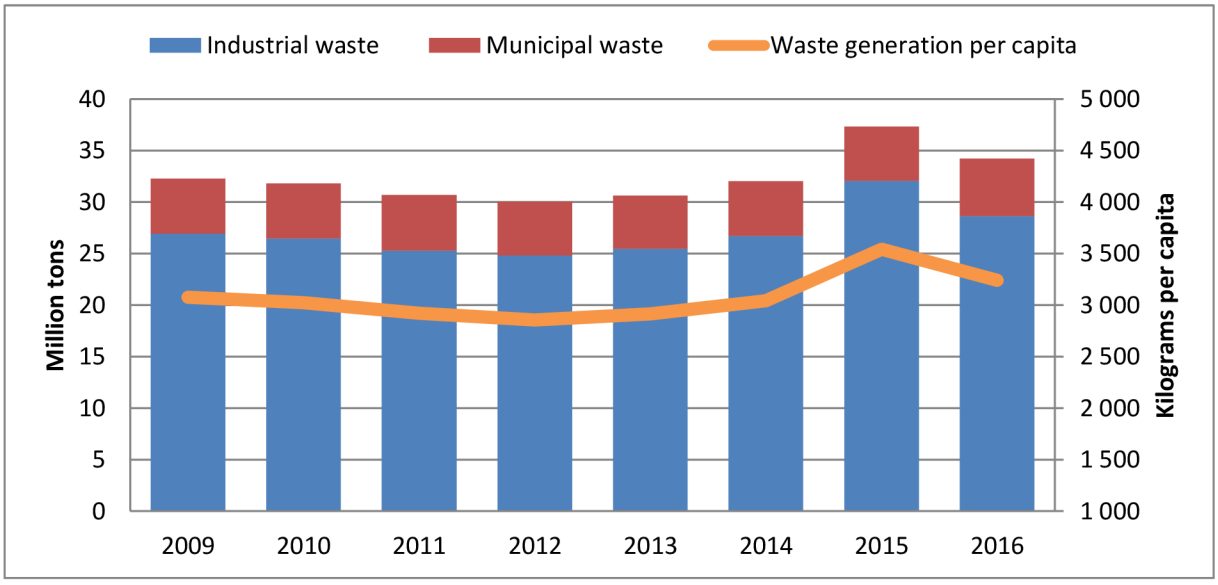
The advantage of this repetitive occurrence of waste management expenditure is that is produces a substantial amount of data that can be quantitatively analyzed. When comparing with the capital expenditure, we often encounter only isolated data points that are often spread wide both in time and space.

From the perspective of historical development, the sum of EPE has practically doubled in the shown time period. Moreover, in relative terms it has grown from somewhere around 1.5% of GDP up to 2.0% of GDP in the recent years (according to the data from the Czech Environmental Information Agency – CENIA, 2017), further stressing the importance of environmental protection from the perspective of the public sector. And out of this sum including both capital and current EPE, current expenditure on waste management represents roughly 40%. Financially-wise, this makes the area of waste management practically the most important part of environmental protection in the Czech Republic.

1.4.2 Waste management in the Czech Republic

In this subchapter I provide overview of the waste management in the Czech Republic. The development of waste generation in the Czech Republic is shown in the Figure 3.

Figure 3: Total waste generation in the Czech Republic, million tons, 2009-2016

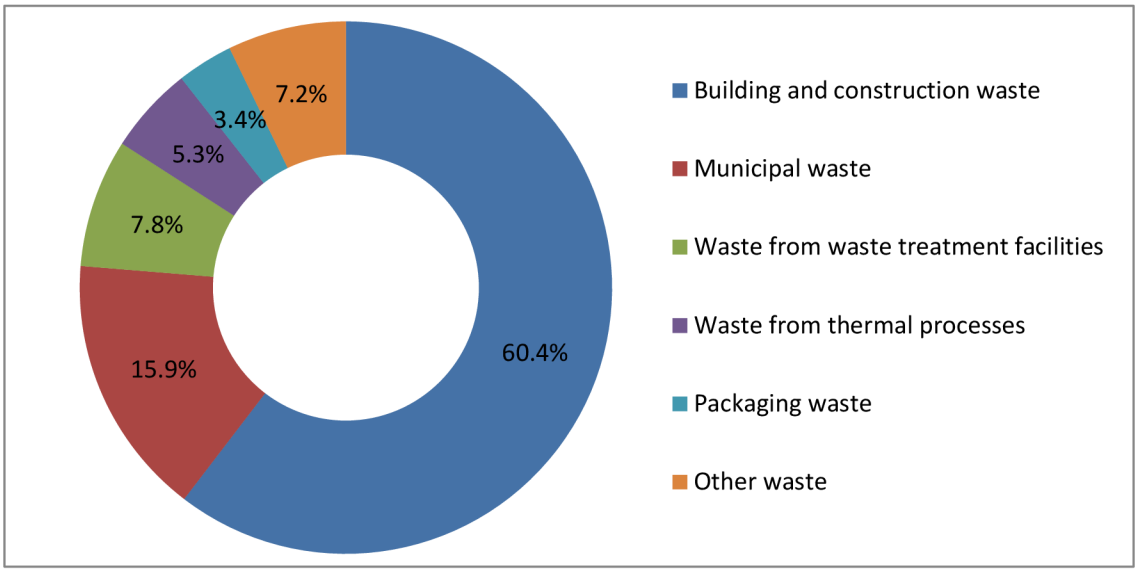


Source: ISOH (2018)

Total generation of waste was in recent years above 30 million tons. However, it is important to differentiate between two main types of waste, which is commercial (industrial) waste and municipal waste. Commercial waste represents practically any kind of waste that is a by-product of commercial activities and can cover anything from office waste to heavy industry waste. Municipal waste, on the other hand, represents, simply put, waste being produced in the municipalities, primarily by the residents, but not from the commercial activities.

Figure 3 shows a large disproportion between these two types of waste. If calculated in relative terms, per capita commercial waste is around 2500 kg, while it is only around 500 kg in case of municipal waste. The reason is that commercial waste covers also extremely heavy waste fractions compared to the standard municipal waste, probably most notably demolition, or in general building and construction waste. While taking relatively little volume, weight-wise can this waste fraction be very significant. For instance, partial reconstruction of an apartment can generate demolition waste of several tons, while the whole family living there might not generate even one ton of municipal waste during the whole year. The total amount of generated waste thus heavily depends on the type of prevailing industry in the country, and can be significantly different even between the various regions. Relative comparison of waste generation by categories is shown in the Figure 4, where municipal waste accounts for around 16% of the total waste, while building and construction waste takes up more than 60%.

Figure 4: Waste generation in the Czech Republic in 2016 by categories



Source: MŽP (2017d:253)

Another distinction between commercial and municipal waste is in the responsibility for the waste and subsequently the costs of the waste treatment. According to the Czech Waste Act, commercial waste is responsibility of the commercial body that generated it and this body is also required to cover the related costs. This practically means that it is in the best interest of the commercial bodies to efficiently deal with their waste and seek for any possibilities of either reducing the total amount of waste generated by them or somehow utilizing the waste, once it had been generated. These commercial bodies also directly contract the waste management (WM) companies and pay for the collection and treatment of their waste.

On the other hand, municipal waste is, according to the Czech Waste Act, the responsibility of the municipality. While it is clear that it is actually citizens who generate the waste, it is the municipality that has to secure waste collection and the subsequent treatment. In terms of costs that are naturally part of this process, it is again the municipality that has to pay for it. However, the municipality can raise revenues for WM from legal municipal fees it is allowed to charge to the citizens. This WM fee is defined in the relevant legislation and it is then up to the municipality to collect it and cover the WM expenditure with it. But municipality cannot set the fee at whatever level it decides to. First, Waste Act defines how municipality is supposed to calculate this fee, including certain limits. And second, setting up basically any municipal fee is also a political decision and higher fees are naturally connected with the negative reactions. Municipalities therefore try to balance the fee level between sufficient to cover the MW costs and being politically passable. Nevertheless, the sole fact that it is the public finance that is used to cover the expenses of municipal waste management brings up the question of efficiency and the factors that influence it. In the rest of the thesis I will focus on the municipal waste managements and examine what affects the efficiency in this area.

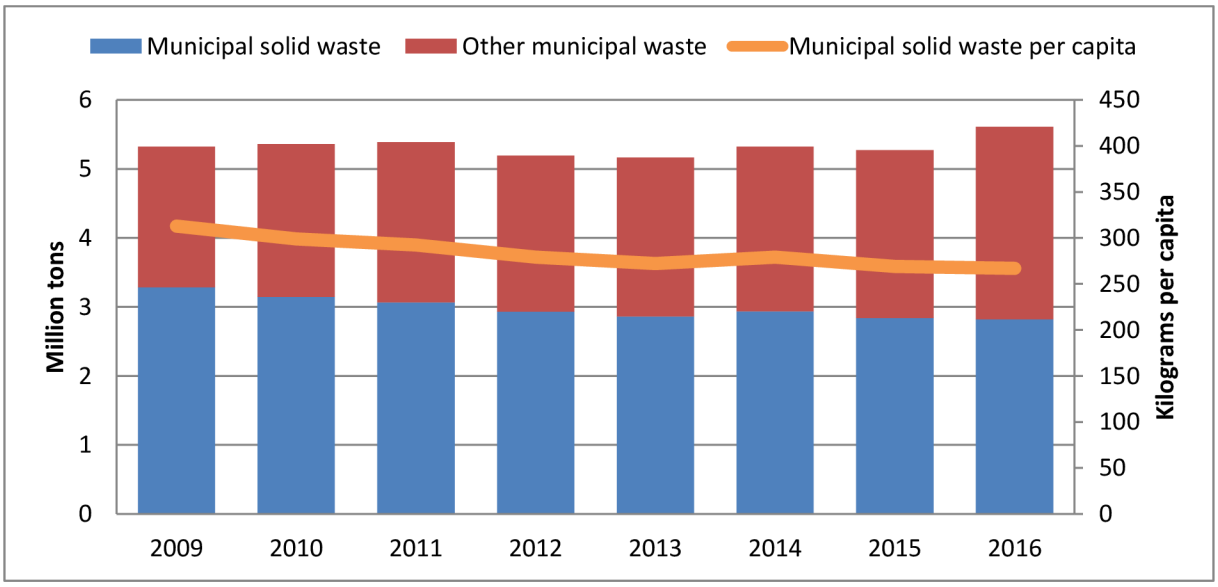
1.4.3 Waste management in the Czech municipalities

Czech Waste Act (Act 185/2001. Coll.) defines in Part 1, §4(1)x that the municipality is the originator and the owner of the municipal waste since the very moment this waste has been discarded in the designed place (excluding commercial waste, as was described above). This practically means that, independently from whoever produced the waste in the municipality, it is the municipality that is responsible for the whole process around the waste management. It

is then up to the municipality how its waste management will be set up and it is the municipality that is fully responsible for it. Waste Act further allows the municipality to define its waste management system in the form of a specific local legislative act valid within the limits of that municipality. Specific responsibilities of the municipality include provision of designated places where waste can be stored for later collection. This can differ between the municipalities and also within the municipality based on the housing structure. In the Czech Republic the two most common systems for waste collection are door-to-door collection of individual waste bins in case of family houses and large shared waste bins typical in densely populated areas with apartment buildings. Another responsibility of the municipality is to provide a possibility for separate waste collection for at least hazardous waste, paper and cardboard, plastics, glass, metals and biowaste. Separate collection of additional waste fractions is then up to the individual municipality.

If we then consider only municipal waste, generated amount drops significantly from the figures of the total generated waste. Following Figure 5 shows the development of municipal waste generation in the Czech Republic in recent years.

Figure 5: Municipal waste generation in the Czech Republic, million tons, 2009-2016



Source: ISOH (2018)

Total amount of generated municipal waste in recent years is stable at around 5 million tons annually. It can be split into two categories of municipal solid waste and other municipal waste that differ in the actual origin of the waste. Other municipal waste represents waste that is produced in the municipality, but does not end up in waste bins for mixed waste assigned to the households. Practically it covers waste generated during street cleanings, waste from public bins and other kinds of waste that is generated in the municipality but not the one in the bins assigned to the dwellings. It also covers separated waste than is collected in the specially designated bins for recyclable waste, including for instance paper and cardboard, plastics, glass or biowaste. Figure 5 shows that this kind of waste is slowly growing in the recent years, which is likely the result of the improving waste separation in the Czech Republic.

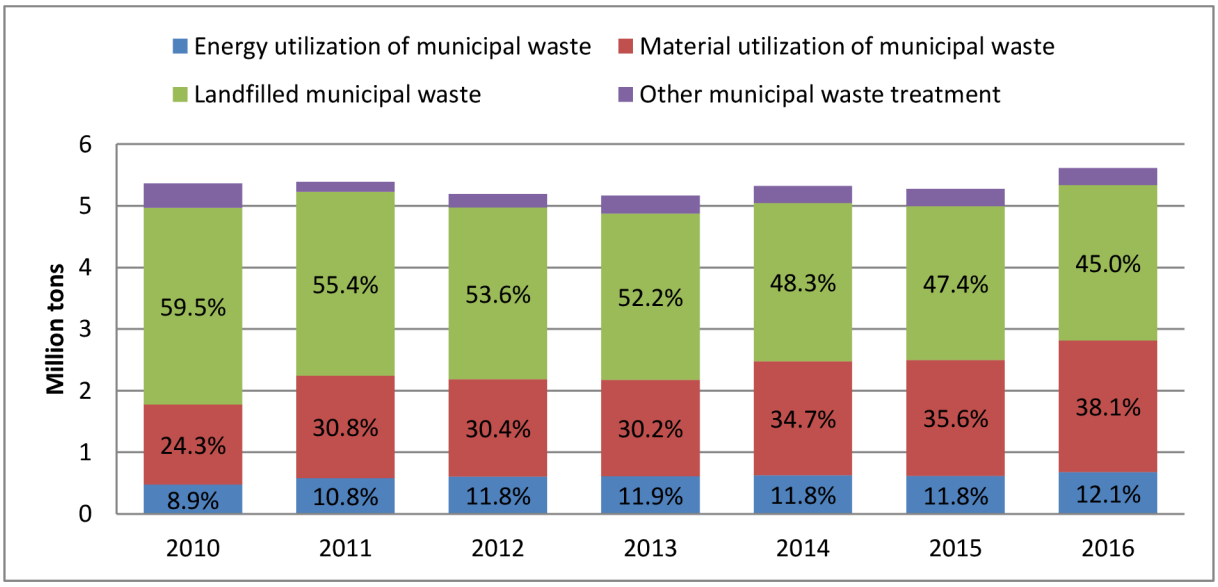
Municipal solid waste, on the other hand, represents the waste directly produced by the people in the municipality and ending up in the mixed waste bins located usually next to the individual dwellings. Figure 5 shows that the amount of this waste is slowly decreasing. As was mentioned, this is likely at least partially caused by the improving waste separation. There is a clear connection between the two – the more people separate waste, the less mixed residual waste they generate. Other reasons for decreasing mixed waste generation might be changes in the behavior of the people, like preferring consumption of products causing less waste (reusable products, less packaging waste, etc.).

Difference between these two categories of waste becomes obvious when it comes to the costs they generate. Other municipal waste is usually much better separated into the relatively homogenous waste streams. For instance, if we have collected recyclables, these could be often directly used for extracting secondary raw materials or otherwise valorized. Collected biowaste can be often used straight away for composting or biogas generation, paper, glass and plastics can be after little treatment used for recycling and so on. This means that these kinds of waste are very likely to become a resource for further production and often can induce more revenues than costs. In the Czech Republic most of the municipalities have a contract with authorized packaging company EKOKOM and get paid some money based on the amount of waste they separate while paying some fees for the separate waste collection. Depending on the collected amount, waste separation can be for the municipality in the end profitable. Alternatively, municipality can take collected recyclables directly to the material

recovering facility and get paid for it. In case of biowaste, municipality can set up its own composting plant or biogas plant and either get revenues from selling the product or utilize the product for its own purposes. In the end, if the process for further treatment of separated waste is set correctly, instead of only costs it can generate also revenues for the municipality.

On the other hand, mixed residual waste does not generally provide any ways of generating revenues from this stream. After the collection is such waste transported and undergoes further treatment, usually in the landfill or incinerator. Compared to collected recyclables, unit costs are usually several times higher, making mixed waste practically the most expensive waste stream to treat (excluding some special types of hazardous waste, that public usually does not deal with). From the perspective of municipality it is then preferable to have more separated waste instead of mixed waste. Besides environmental benefits it can also lead to notably lower municipal solid waste expenditures (typically in the sense of lower payments to the WM company), for instance as a result lower frequency of mixed waste collection, as less mixed per capita is generated. Factors that can lead to increased separated to mixed waste ratio are examined in more detail in later parts of this thesis.

Figure 6: Municipal waste treatment in the Czech Republic, million tons, 2010-2016



Source: MŽP (2017c:71)

In terms of waste treatment, two most common ways of dealing with municipal waste are landfilling of predominantly mixed waste and material utilization of typically separated waste. Third, slowly growing category is energy utilization, usually meaning incineration of the waste in order to generate energy. Other ways of municipal waste treatment (like incineration without energy utilization) represent marginal ways of waste treatment. Division of municipal waste according to the type of waste treatment is shown in the Figure 6. Compared to the other European countries, large percentage of waste landfilling represents a problem with respect to achieving specific environmental targets set by the European Union, even though this indicator dropped notably in the recent years. However, current levels of fees for different types of waste treatment in the Czech Republic make it difficult to further decrease landfilling, as it is the cheapest option for dealing with the mixed municipal waste and WM companies naturally respond to that. Compared to some other countries in EU, landfilling fees there are sometimes double or even quadruple. However, an alternative in the form of energy utilization requires significant investments into the new infrastructure, while currently existing capacities already operate at the designed level. Another issue is also the distance factor, as the frequency of existing landfills is also much higher in comparison with only few thermal treatment plants for municipal waste, which makes energy utilization of the municipal waste even more expensive due to the transportation costs. Nevertheless, current national waste management plan counts with gradual increase of the landfilling fees which should divert current waste stream more towards other treatment options than landfilling.

In terms of securing municipal solid waste management (MSWM) there are few usual options for the municipality. Most of the municipalities choose to contract an external provider of MSWM and pay for the service (either fixed yearly per capita fee or fee based on some quantitative indicator, like generated amount of waste). From the perspective of the municipality this is probably the most comfortable way, as the municipality just has to pay the fee and external company takes care of the rest. Some municipalities contract only certain parts of the MSWM services, for instance service related to mixed municipal waste, and take care of waste separation on their own, or contract a different company for this, but that is up to the municipality. The other, much less common option is to have a municipal company that takes care of MSWM. Such company usually takes care also of other technical services in the municipality. These are likely to be found in larger municipalities, where economies of scale

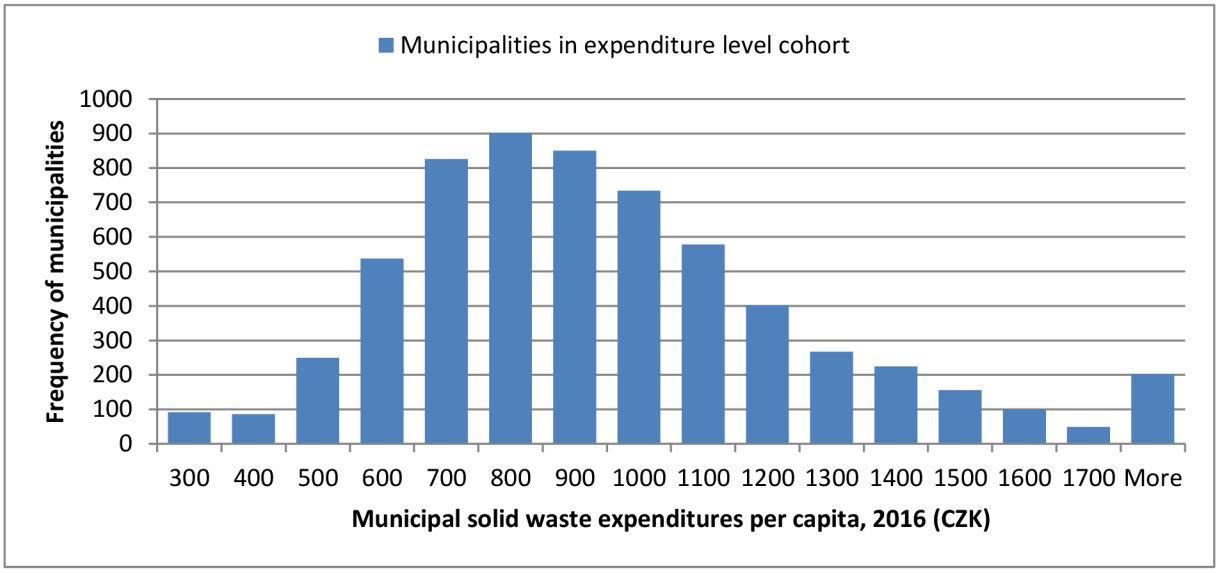
make it economically viable to have such municipal company. Alternatively, some of these municipal companies historically evolved and besides home municipality provide service also to several surrounding municipalities at fully commercial basis in order to better utilize their capacity and again take advantage of economies of scale. In case of more common external providers, the companies can be divided based on their ownership. There are privately owned, publicly owned (usually by a group of municipalities), with mixed ownership (part is private, part is owned by the municipality or a group of municipalities), or already mentioned municipal companies.

Municipality is responsible for financing MSWM. In order to do that, it has the option of charging its citizens with related waste fee (technically municipality can either charge a local fee for municipal waste system or a so called waste management fee – I will not go into details of legal differences between the two, as it is not important for our purposes and a large majority of municipalities use the first type – the local fee, while the other is relatively rare). While majority of the municipalities choose to charge such fee, it is not obligatory and some municipalities finance their WM from different sources, depending on the local specifics. Examples include raising other, for instance property taxes (well applicable if there is a significant amount of commercial activity in the municipality). And some municipalities do not need to collect waste fees or local taxes at all, as they get sufficient resources from the central budget based on the current system of tax assignment to the local governments (typically if some local corporations or residents pay substantial income taxes and the municipality that gets part of it is relatively small).

Nevertheless, large majority of the municipalities charge waste fees. These are typically calculated as annual fee per capita, sometimes with discounts for some specified groups of people (elderly, children, etc.). This type of fee represents a flat fee that does not reflect individual waste behavior. On the other hand, it is possible use "*performance-based*" fees that reflect, for instance, how much waste one produces or alternatively how much waste one separates. This issue is examined in more detail later in the thesis. In case of most common flat fee per capita, the municipality is limited by the legislation when setting the level. Until 2012 this limit was 250 CZK base fee plus up to another 250 CZK depending on the actual municipal waste expenditure. Since 2013 was this limit raised to 250 CZK base fee plus up to

750 CZK variable part. Thus maximum level of waste fee charged by the municipality can go as high as 1000 CZK per capita per year. However, majority of municipalities charge lower fees, even though it does not sufficiently cover their WM expenditures. There are several reasons for that. First one is that variable part of the fee can be calculated from the municipal expenditure on solid waste, which represents only part of the municipal waste expenditure, even though it is usually the largest part. The rest of the municipal WM expenditure has to be then covered by the fixed 250 CZK per capita part. If these other costs are higher, municipality has to find other sources for financing them, but cannot raise variable part of the fee higher that the level calculated from the solid waste expenditure. In a practical example, let us say that total per capita municipal waste expenditure is 800 CZK, but out of this amount only 500 is represented by the solid waste expenditure. In such case municipality can set the local fee to be 250 CZK fixed part plus 500 CZK variable part, resulting in 750 CZK per capita total fee. The remaining gap of 50 CZK has then to be covered from other municipal sources, even though the fee level is not at its top limit. And the second reason for charging lower waste fees is political. People generally dislike any tax or fees increase and waste fees are no exceptions. This political aspect was strongly present in 2013, once municipalities could charge much higher waste fees, but most of them did not raised the fee level as high as they could according to the variable part calculation (or did not raised it at all), as they did not want to upset their citizens.

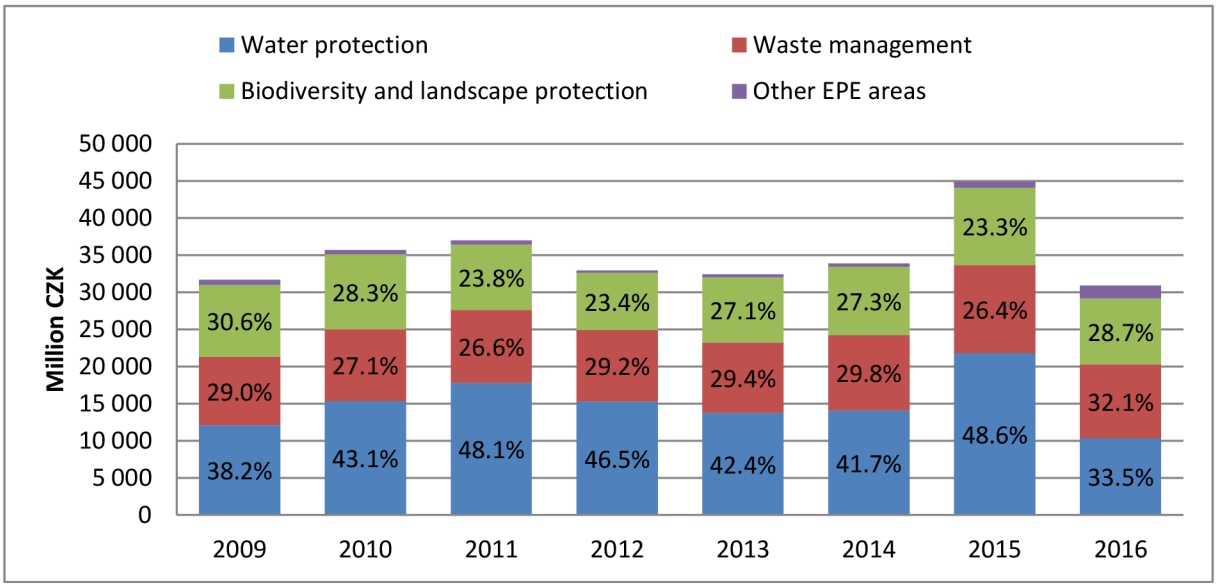
Figure 7: Histogram of Czech municipal solid waste expenditure per capita, 2016



Source: own calculations based on MONITOR and CZSO

Figure 7 shows the calculated frequency of per capita municipal expenditure on waste management in 2016 from all 6254 Czech municipalities that reported their waste management expenditure. The average per capita expenditure was 927 CZK and median value was 849 CZK. More than half of the municipalities had per capita expenditure in 700-1100 CZK range. However, over 43% of municipalities had average per capita expenditure higher than 1000 CZK. Considering the maximum fee level set by the legislation, it means that more than 40% of municipalities had to partially finance their WM even if they set the fee level at the allowed maximum. However, majority of the municipalities have their waste management fee set at much lower level, usually around 600-700 CZK (plus not including discounts for some specific groups and the fact that the municipal fee collection rate is typically lower than 100%). This results in the observation that majority of the municipalities need to co-finance their WM from some other sources, that could not therefore be used for other purposes, as municipality is by law responsible for its WM independently from how it raises revenues for it. Overall number suggest that municipalities have to co-finance somewhat around 30% of WM expenditure, but there are naturally outliers on both sides with municipalities that are fully able to finance their WM from collected fees, as well as those that finance large majority of WM expenditure from other sources than collected fees.

Figure 8: Development of municipal environmental protection expenditure by categories, 2009-16

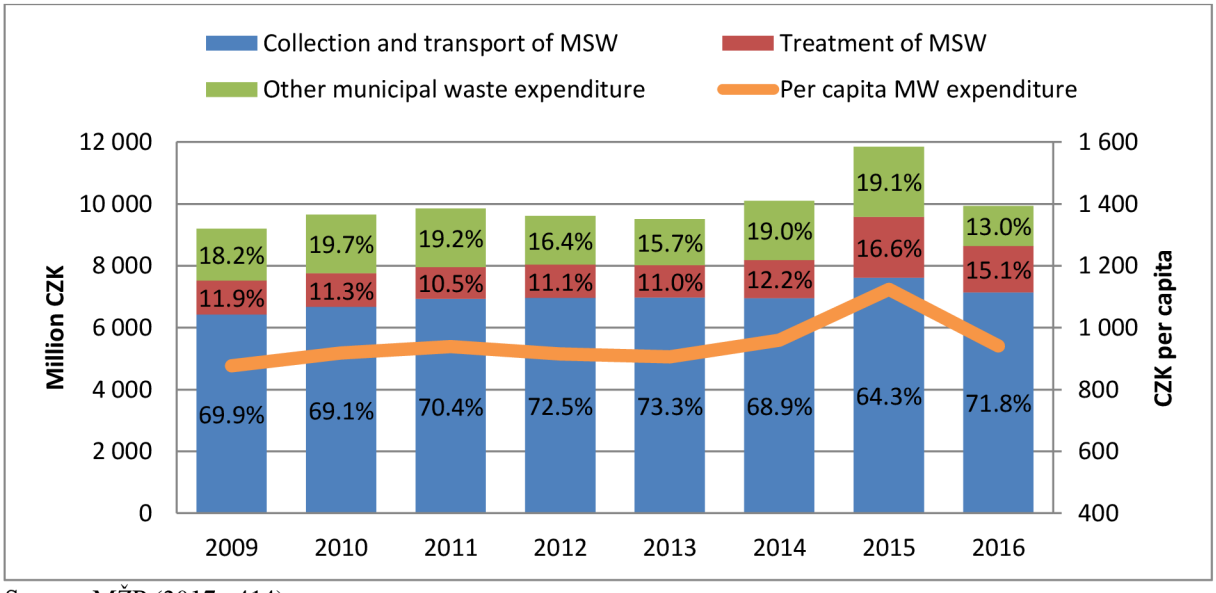


Source: MŽP (2017c:414)

I provide Figure 8 in order to illustrate the overall importance of WM among other categories of municipal EPE (values are in the current prices). WM expenditure represents more than a quarter of total EPE. However, as was mentioned earlier, waste expenditures are mostly current, while other EPE are mostly capital. This can be seen especially in case of water protection (including wastewater) that fluctuates notably in various years while the WM expenditure remains at around 9-10 billion CZK each year.

If we look even further into the structure of municipal waste expenditure in Figure 9, we see that usually more than 70% of expenditure goes to the collection and transport that is directly related to the waste generation by the citizens. But here I need to note that based on the experience from collecting the data from the municipalities, this division of expenditure might not be always accurate, as some municipalities simply do not bother with more precise reporting of their WM expenditure into individual categories and report everything under collection and transport category. In the end these expenditures are still waste expenditure, but the assignation to the specific categories might not be that precise.

Figure 9: Development of municipal waste management expenditure by categories, 2009-16



Source: MŽP (2017c:414)

In practice, municipal WM is set up mostly in the following way. Practically each house in the Czech Republic has its own mixed residual waste bin (door-to-door collection). In case of single family houses these are bins with volume of mostly 110-240 liters, while in case of multifamily apartment buildings there are usually one or more larger bins with volume of

1100 liters. Sometimes there are multiple mixed waste bins available, especially in case of larger apartment buildings. Contracted WM company then comes in scheduled times to collect this waste and transport it for the further treatment, usually landfill or incinerator, with the possibility of further intermediate mechanical-biological treatment for additional separation of selected waste fractions. Frequency depends on the specific contract between the municipality and the WM company. In case of smaller municipalities consisting primarily of single family houses it is usually every week or every fortnight, occasionally less frequent, and sometimes alternating with biowaste collection, if such bins for houses are used in the municipality. Also, in parts of larger municipalities with comparable housing structure is this collection frequency usually every week. In case of apartment buildings that are usually found in larger municipalities, the provided large bins are emptied more frequently, typically twice a week, as there is generally much less available bin capacity per person generating waste due to the limited space around these buildings. Increased frequency of waste collection naturally results in higher municipal WM costs.

In addition to the mixed residual waste, municipalities provide also options for separate waste collection. In practically every municipality in the Czech Republic it is possible to separate paper and cardboard, plastics and glass, and since 2015 also biowaste (green municipal waste). These are usually collected at designed drop-off sites at one or multiple locations in the municipality (depending on the size of the municipality) and consist of several larger colored containers for each waste fraction that are usually also collected by contracted WM company (but this can be contracted separately). There is not a single rule of where these drop-off sites are located or how many bins they should contain – it depends solely on the decision of the municipality as it needs to respect the space limitation and the usual amount of the incoming waste. In some cases, typically in small municipalities, there is only one bin for each waste fraction emptied every month. On the other hand, some municipalities might have a large drop-off site with 10+ containers that are emptied practically every week and can include bins for other separately collected waste fractions as well. In addition to that, larger municipalities (usually 1000+ citizens) have often at least one household waste recycling center (HWRC) with professional staff that provides additional options for waste separation, including bulky waste, WEEE (waste electrical and electronic equipment), metals and so on. In comparison with drop-off sites HWRCs offer better options for waste separation, but are

also limited by the opening hours that can vary from few hours per weeks in case of smallest to those open practically every day from morning to evening in case of the largest ones. In some municipalities there is an alternative to the drop-off sites in the form of kerbside collection of selected recyclables (usually paper and cardboard and plastics). And finally, the municipality is required to collect hazardous waste at least twice a year or provide a safe place where people can dispose of it. Besides that it is up to the municipality to provide options for collecting other waste fractions, either by using stationary collection points or regularly scheduled collection.

In addition to that, there is also mentioned other municipal waste that people do not directly dispose of but is still generated in the municipality. This includes waste like street sweepings, waste from public bins or other waste from public spaces (including green waste). Collection, transport and treatment of all this mixed municipal waste, separated waste and other municipal waste sum up to the total waste expenditure that municipality has to cover, with the primary role played by the mixed municipal waste. My goal in this thesis is to explore what are the factors that affect the efficiency of the municipalities in this area. I will focus specifically on the expenditure side of the municipal WM and examine what are the reasons and factors that cause notably different efficiency (expressed typically by the per capita municipal waste expenditure) in various municipalities. While doing so I will try to identify both those factors that cause higher expenditures (and thus decreasing the efficiency) and those that cause lower expenditure (and thus increasing the efficiency).

1.5 Efficiency in the municipal waste management – literature overview

In this subchapter I provide an overview of the relevant studies that examined efficiency in the field of waste management. Most of the included studies use frontier analysis methods (namely DEA and SFA) that are suitable for examining a complex issue of efficiency in cases where multiple inputs and outputs come into play. Both Czech and foreign studies are included. First group of the studies focuses primarily on the organizational form of WM service provision, second group employs primarily statistical methods for identifying relevant factors and last group of studies is included in order to show the variability of the potential

efficiency factors that might have important influence on WM. The objective of this subchapter is both to provide overview of the available research in this area and to identify potential efficiency factors that would be later examined using available data collected for this study.

Bel and Warner (2008) published a review in which they examined studies dealing with the effect of privatization with respect to the cost reduction in WM. Generally they have found little support for a link between privatization and cost savings, resp. the observed savings are not systematical. The issue identified in the review is that in the research is rather too much focus on the competition, which actually might not work that well in quasi markets, such as municipal waste management provision. An important comment in the study is that with absent competition, ownership makes little difference on costs borne by the municipalities. Study then concludes that there is no systematical optimal choice between public and private delivery of the service, and responsible managers should thus approach the issue in a pragmatic way. Cost savings are simply not systematically found if looking at the issue from company organizational type. Specifically, waste collection is characterized by weak competition or collusion due to the trend to concentration in the market. According to the authors, public vs. private debate places too much emphasis on the ownership when primary attention should be given to the market structure, regulations, incentives and the level of contract completeness. In waste collection weak competition between companies erodes any potential cost savings. Authors suggest that the debate on privatization needs to move beyond a debate on competition and ownership and instead look more closely at the costs of contracting and the organization of service itself. These are considered the primary features that will determine cost savings, whether under public or private production. The reasons why private sector fails to deliver consistent cost savings is a result of inadequacy of the theoretical framework based primarily on assumption about competition and ownership.

In the Czech conditions efficiency of waste management as a public service was examined in more detailed by Ochrana et al. (2007), who focused on the role of the WM company organizational form factor in the efficiency of the service. Study analyzed which form of service provision is preferred, which criteria are important when selecting WM provider and what reasons can lead to the change of the WM provider. Authors collected more than 900

survey replies from Czech municipalities and analyzed the answers together with the available data about related municipal expenditure. The outcome of the study is that that the own production of services is the most efficient, but this is due to the fact that certain related costs of the service production are not directly assigned to the production of these services by the municipalities, and therefore the reported expenditures are undervalued. Using only expenditures directly reported by the municipalities on these services is thus incorrect when comparing with the external provision of these services. The least efficient, on the other hand, are municipal companies that were arbitrary selected without any competition. But as long as the competition exists, the form of ownership actually might not matter at all, as all companies compete among them.

There are more available studies from the Czech Republic that focused specifically on contracting out selected public services (including waste management), with the conclusion being basically in accordance with studies already mentioned. Meričková Mikušová et al. (2017) examined various aspect of contracting-out public services in Slovakia and Czech Republic. Authors here compare own and external production of selected public services (including waste management) in the sense of question whether to make or to buy the service? Study then verifies the hypothesis whether the contracting actually improves the effectiveness of selected service delivery. Based on quantitative data analysis, this hypothesis was not confirmed, both in Slovakia and the Czech Republic. Nemec et al. (2007) examined implementation of contracting-out on the local level in Slovakia and the Czech Republic for several public services, including WM. Study concludes that level of contracting-out is in both countries relatively high, but the positive impacts from this type of public service provision were not proved in either country. The main issues seen by the authors are in the contractor selection process, less focus on the quality and potentially corruption. Suggested solutions include pursuance of increased transparency, regular testing of service arrangements and necessity to improved public procurement standards. Finally, Merickova et al. (2014) based on the data from the Czech Republic and Slovakia again do not confirm that either internal or external provision is of waste management is better and the focus should move beyond the public vs. private provision debate, as already suggested by previously mentioned studies.

Worthington and Dollery (2001) examined efficiency of MSWM using data of 103 local governments in Australia. Study uses DEA with inputs including number of properties with WM service, population density, cost index, occupancy rate (people per household), population distribution and expenditure, while outputs included total waste, recyclable waste and recycling rate. Provided results suggest that the WM inputs could be reduced to 65% based on the observed best-practice while the productivity losses due to the scale effect were estimated to account for 15% of total inputs. Study also suggests that strong inefficiency can be in urban municipalities caused by the congestion and other issues related with high population density, while in case of rural municipalities is the main problem the inability to attain an optimal scale of operations. Comparable to this study is Domberger et al. (1986) from UK who used collection frequency, population density and distance to disposal sites in their costs function. As an output they used units serviced (pickup points) instead of population, as the number of pickup points seemed to the authors as more important than number of serviced people. Then density was again identified as having negative impact on total costs although the lower proximity would suggest lower costs.

De Jaeger et al. (2011) published a study in which they examined impacts of some local policies aimed at MSW cost reduction (basically on efficiency). DEA was used in order to identify important efficiency factors. Used sample included 299 municipalities in Belgium. Better results in terms of acquired efficiency were exhibited by municipalities that are members of joint ventures focused on waste collection (WM outsourcing), or members of voluntary agreements to reduce MSW. Different frequency or using of weight-based pricing system appears to have no impact on the efficiency, but in this case the authors were comparing weight-based pricing and pricing per bag and not system with and without unit pricing, in which cases adoption of unit-based pricing tend to have a very significant effect on the waste behavior of the people. Overall, results show that aiming at the MSW reduction does not lead to lower efficiency of public service provision, on contrary. Used DEA model included inputs of costs and outputs of residual waste and 4 other variables standing for different types of recyclable waste fractions. After calculation of efficiency scores authors analyzed effects of additional variables like population characteristics, density, political orientation and income, what represents a common multiple-stage DEA approach. According to the results, young and old people have positive effects on the efficiency, population density

has negative effect, what is comparable with observation by Worthington, Dollery (2001) that densely populated areas suffer from congestion which in practice offsets any efficiency gains from relative shorter distances to waste pick-up points. Finally political orientation towards left spectrum was also identified as having strong positive effect on the efficiency.

Rogge and De Jaeger (2012) used a modified DEA for evaluating efficiency of municipal WM using data from 239 municipalities in Belgium. Modified DEA was used as authors criticize the limited explanation power of the basic DEA models, especially considering increasing complexity of MSWM. Inputs in the constructed models were municipal expenditures, while outputs were various types of collected waste fraction – residual waste, green waste, bulky waste, packaging waste and other waste categories. In addition, 6 background characteristics of the municipalities (population, density, income, collection frequency, pricing scheme and number of collected waste fraction) were analyzed against efficiency scores of selected municipalities, as it is common in multiple-stage DEA approach. However, this study was more of a demonstration of the modified DEA model that a study focused on identification of important factors affecting efficiency and little results have been drawn. Following this study, authors used practically the same model in Rogge and De Jaeger (2013) where the second stage analysis of additional municipal characteristics is more thorough and uses background characteristics such as percentage of old people and young people, median income, political orientation, collection frequency and waste payment scheme. Based on this municipalities were then divided into categories like residential, rural major centers, etc. Significant and negative factors were identified to be the percentage of young people in the population, political orientation towards green and social political parties, while results for the income were mixed. Second presented model focused more on billing system and collection frequency and was not corrected for demographic characteristics. Significant and positive variables were then identified to be income level, and political orientation towards green and social parties. Again, study does not provide any clear policy recommendations or identify efficiency factors suitable for adoption, as this was not the primary objective of the authors.

Simões et al. (2010) computes the influence of selected variables on the efficiency of the Portuguese urban solid waste services using DEA. Evaluated units were waste utilities – these

could be understood (after simplification) as companies (in the form of concessions, private, or controlled directly by the state) providing waste management services. Variables used in the model were operational and capital costs as inputs, and treated solid waste and recycled waste as outputs. As explanatory variables were used GDP per capita, distance to the treatment facilities, population density, regulation, type of management, composting and incineration services. The identified inefficiencies were relatively significant and notable reduction in costs could be potentially achieved. Theoretical optimal size of the system of WM was at around 300,000 inhabitants. Strong regulation seems to be important as well, as it sets certain levels for the services and contributes to the improvement and quality of the service provided. Negative effects on performance were identified in case of rural areas or high density population. Private utilities seem to be performing better public ones. Composting and incineration also resulted in positive effects, even though in case of incineration it was predictable.

Bosch et al. (2000) analyzed efficiency WM of 75 Spanish municipalities in Catalonia region using DEA, SFA and deterministic frontier method. Inputs used were containers, vehicles and covered kilometers. Outputs included biowaste, which was perceived as the most important waste fraction in Spanish case. Focus of the study was primarily on the method comparison. Based on that, DEA was considered to be the best method, as it is flexible enough to compute specific features of the production process, unlike more rigid formulated models. In terms of important factors influencing efficiency, authors stress that presence of competition seems to be more important than private-public management dichotomy.

García-Sánchez (2008) examined performance of WM and street cleaning in 38 Spanish municipalities with population over 50,000. Study uses common two-stage DEA approach with inputs staff, vehicles and containers and outputs being waste tonnage, collection points, collection points density and km of washed surface area. After initial calculation of the efficiency scores, significance of selected factors was examined in the calculation of an efficiency index. These factors included population, tourist index, mean town temperature, surface area of the municipality, population density, per capita income, economic activity index and prevailing political ideology of the municipal population. Results show that there is a potential for improvement estimated up to 8% reduction in the inputs. Considering the

analyzed factors in the subsequent analysis, only tourist index proved to be significant. Additionally study asks whether public vs. private waste management of the WM company makes a difference with the results showing that the distribution of acquired efficiency among them is identical and does not show that either of them is optimal.

Benito-López et al. (2011) used DEA for identifying determinants of efficiency in the provision of municipal waste management and street cleaning using data of over 1000 Spanish municipalities. Input in DEA model was per capita costs and outputs were residual waste and a specific WM quality indicator (responsivity of the provided service). Additional sociodemographic factors were used in the second stage of DEA in order to identify factors with potential effect on the efficiency. Significant and positive variables were identified to be per capita income, index of tourism importance, general economic activity in the municipality and the prevailing political orientation of the population towards progressive parties. Negative effect was again identified in case of population density.

Passarini et al. (2011) examined indicators of WM efficiency related to different territorial conditions of municipalities using data from a selected Italian region. Performance indicator percentage of waste separation was used for evaluating performance of WM systems. This was tested against income variables in a correlation analysis, but no significant relationship was identified. With respect to territorial variables, municipalities located in plains showed both higher waste generation and separation, while those on the hills produced less waste but had also lower separation percentage – effective collection service is according to the study a problem in hilly areas (the same holds for rural areas). In terms of density, the most efficient seem to be low density municipalities, while most densely populated areas show the worst results.

Guerrini et al. (2017) applied a specific robust non-parametric method introduced by Daraio and Simar (2005) to identify performance drivers of MSWM in 40 Italian municipalities. Input of the model was expenditures and outputs were amount of residual and separated waste. Several exogenous variables were then used in order to examine their relevance considering efficiency of WM. Significant positive factors were identified to be the number of

inhabitants per house and kerbside collection (even though it is more expensive than street bin system. Significant negative factors were the percentage of non-residents, size of the municipality (smaller municipalities are more efficient), density, and tourist flow.

Moore et al. (2005) used DEA to identify efficiency factors in 46 selected US cities over 6 years period in 11 types of municipal services, including waste management, together with multiple potential factors that could influence the efficiency. DEA model for waste management used inputs staff and expenditure, while the outputs were number of citizen served. However, study then does not go any further due to the lack of data for such additional analysis and basically suggests that further studies are to be conducted.

Vishwakarma et al. (2012) used SFA in order to evaluate efficiencies of WM services in selected 22 urban cities in India. Provided model assumes that municipalities want to maximize collected amount of waste using inputs such as labor, costs, density, number of available vehicles and vehicle technology level. Various functional forms of the classical Cobb-Douglas function were used in the model. But study does not go beyond the calculation of the efficiencies and only comments that larger cities tend to have higher efficiency scores and actually that the costs do not seem to affect collection capacities in any municipality. On the other hand, amount of labor and available vehicles has positive effect on the output. Negative effect of the density was identified. The suggestions are then standard comments that the less efficient municipalities should adopt appropriate practices and management models from those that are more efficient, as according to the model they could improve their capacity even without additional inputs. But beyond such general recommendation the study does not provide any specific answer what factors are actually to be adopted.

Huang et al. (2011) analyzed performance of municipal solid waste collection using DEA with the data from 307 local governments in Taiwan. Authors used five "*key performance indicators*" for the evaluation including cost per unit volume of MSW collected, quantity of MSW unit collected per unit collection time, quantity of MSW collected per collection vehicle, population served per collector, and quantity of MSW collected per vehicle-mile. The

result of the study is then information about which local governments perform best among the analyzed sample.

In the Czech conditions Fiala (2007) used DEA to examine WM of 68 municipalities. For each municipality he identified 19 parameters including, for instance, population, amount of solid waste, usage of PAYT charging scheme, rates of landfilling, incinerating, or recycling, expenditure or revenues. Results are presented for selected model, where the inputted parameters were amount of municipal solid waste and expenditures on municipal solid waste treatment while output was amount of separated waste. An observation was made, that main factor of efficiency seemed to be the presence of a PAYT charging scheme.

Finally I include two more studies from developing countries in order to show both the differences and similarities related to the WM. Wilson et al. (2006) examined role of the informal sector in WM in developing countries in order to pride also a bit different view at the WM issue. Waste management in developing countries often heavily relies on the informal sector. The issue in such countries is therefore not how to set up a new system for WM but how to successfully integrate informal sector into the waste management planning. The fact is that, despite the health and social problems associated with the informal recycling, possibility to participate in WM provides significant economic benefits to the people in this informal sector. Experience shows that it can be actually highly counterproductive to establish new formal waste system without taking into account informal system that already exists. The goal then becomes to build on the best practices and experience of the informal sector, while working on improving efficiency and the living and working conditions of those involved. On one hand it is true that such conclusions have a limited validity for purposes of this thesis, as the role of the informal sector in waste management is in the Czech Republic much weaker compared to the developing countries, but on the other hand this still, it provides an interesting insight to the important aspects of waste management that are behind the performance of waste management in a significantly culturally and economically different environment. One thing we can learn from such study is that the informal sector can represent a powerful force in the waste management. It does not have be in the forms of waste pickers, but for instance in the voluntary green watches or the overall movement towards higher waste separation, preference of waste minimization, etc. that can further improve existing waste

management also in developed countries where the formal sector is often expected to be the one and only responsible body for the state of the waste management.

Second study is a review by Guerrero et al. (2013), and provides an interesting insight to the factors that were identified as important in relation to waste management in the studies focused on WM in developing countries. These include factors like family size, education, income, household attitudes towards waste separation, support by the real estate company, community commitment, public participation, fee structure, location of the household, transport practices, route planning, improper bin collection, proper construction of the bins themselves, lack of information about the waste pickup schedule, insufficient infrastructure, poor roads, number of vehicles for waste collection, presence of market for recycled materials, unreliable data about waste management, organization of the informal sector and promotion of micro-enterprises for extending available waste management services and others. As one can see, multiple of them are relevant for developed countries as well.

1.5.1 Identified factors of efficiency

Based on the provided literature overview I have identified potential efficiency factors that seem to appear most frequently. I will divide the factors into two groups according to their potential for further research from my perspective.

First group of efficiency factors includes those that can be either somehow directly influenced by the municipality or can be relatively easily predicted, thus municipality can use this knowledge in order to adjust the existing WM accordingly. These efficiency factors include presence of competition, type of WM company ownership, waste collection frequency, availability of kerbside collection and incentive programs, population density, rurality of the municipality, territorial conditions and its age and household structure. In case of some listed factors the effects are relatively easy to predict, for instance higher collection frequency directly translates to higher expenditure, while in case of other like presence of incentive programs, are the resulting effects on WM less clear.

The second group of factors includes those that are likely beyond the direct influence of the municipality or are primarily affected by some external factors making them difficult to predict. These second group of factors include political orientation, income of the people, amount of tourists, general economic activity in the municipality, household occupancy or the amount of non-residents in the municipality. This second group of factor includes basically those are somehow defined, but generally municipality cannot do that much about them, so they offer mostly ex-post explanation of the acquired efficiency results and their utilization for planning WM in a municipality is more limited.

Important note here is that provided literature overview has its limits. As one can see, many of the studies are focused on the same countries and thus the identified efficiency factors can be biased. But this is also the problem of the overall availability of such studies from various countries, especially if research in this area is not being done in other countries. If studies for other countries were available, factors could have been different, as suggested by including last two studies of WM in developing countries. However, in my opinion, provided studies could be relatively well applied to the Czech condition, thus the identified factors should be mostly relevant as well.

2 MUNICIPAL SOLID WASTE MANAGEMENT IN THE SOUTH MORAVIAN REGION

The purpose of this chapter is to generally describe the waste management in the South Moravian Region in the Czech Republic. I have selected this region for collecting municipal waste management data from individual municipalities. First parts of the chapter contains detailed description of the data collection process from available databases and individual municipalities, which was necessary, as significant amount of the utilized data is available only directly from the municipalities and is not present in any centralized database. The final parts of the chapter include description of the collected data and additional extensive list of qualitative findings obtained during the data collection.

In this thesis I primarily perform analysis of the quantitative data, or the data that could have been transformed from the qualitative to the quantitative (usually in the form of a dummy variable). However, as one can see from the list of additional qualitative findings from the interviews with the municipal representatives including notes, opinions, comments, etc., there is a substantial amount of factors that can have a notable influence in municipal waste management, but are either difficult to be included in the quantitative analysis or are too much municipality-specific. Nevertheless, I include these findings, as in my opinion they are of value and importance when trying to understand better MSWM, and in order to show the variety of factors that can influence waste management in the individual municipalities.

2.1 South Moravian Region in the Czech Republic

South Moravian Region is located in the southeast part of the Czech Republic and borders with Austria and Slovakia. Regional capital Brno is the second largest city in the Czech Republic. It is home to several universities and research centers and is well known for trade fair center with a long history. Region has very good transport connection with neighboring countries and capitals (Prague, Vienna, Bratislava) both by car and train. Region has increasing potential in the areas of computer technology, telecommunications, software development, biotechnology and other high-tech fields, thanks to the strong impact of the universities in the region. Besides that more than 60% of the area is agriculture land, of which 83% is arable. The region is also well known for winegrowing (90% of vineyards in the

Czech Republic are located in this region, including numerous small wine producers). Region offers also large potential for tourism, especially in summer thanks to the relatively warm climate (warmest in the Czech Republic) and many historical and cultural sites, together with several protected natural areas (Jihomoravský kraj, 2018). Basic data are provided in Table 3.

Table 3: Basic data about South Moravian Region, 2017

Size	7187.8 km^2
Population	1 178 815
Population density	164 inhabitants/km^2
Number of municipalities	673
Number of towns and cities	49
Districts	7
Regional capital	Brno (population 377 973)
Highest and lowest points	836m and 150m

Source: Jihomoravský kraj (2018)

Concerning the focus of my research, this region offers large amount of municipalities that produce a large dataset, the region includes municipalities from very small with few dozen citizens to towns with over 10 000 citizens, municipalities are located both in rural areas and on the suburbs of large towns with most of them being at relatively close physical distance from the center of the region. Such variety of municipalities offers also large variety of ways how to deal with the municipal waste management with many of them being unique and inspiring. The rest of the chapter provides a detailed description of the whole data collecting process together with the basic description of the collected data.

2.2 Background of the data collection

My first question when considering the analysis of MSWM was what data to analyze. The basic data to collect when examining MSWM are obvious – the amount of generated waste and the expenditures, as I am looking at MSWM from the economic perspective.

The amount of waste in municipalities is typically measured in tons per year. As there are multiple waste streams that are generated in the municipality, I had to differentiate between them. Description of what kinds of wastes are collected in the municipalities is provided in

the chapter 1. The basic distinction between the fractions of municipal waste can be defined for our purposes as the waste that is being separately collected with possible later recycling or energy utilization, and residual mixed waste that ends up in the landfill or in the incinerator.

With residual mixed waste is the situation from the perspective of data collection simple, as it consists of just one category (20 03 01 – mixed municipal waste, according to the waste catalogue[5]). With recyclables comes the problem that there is no one unified system how different fractions are collected. Especially large municipalities collect and report a wide variety of waste fractions, while some small municipalities collect and report only few fractions besides residual waste, and some municipalities not even those. Thus in case of recyclables we are dealing with a notably heterogeneous data. While the information is available for multiple waste fractions, in order to have comparable data I have focused only on selected waste fractions that are most commonly collected by the municipalities. Besides obvious residual mixed waste, the most common fractions are plastics, paper and cardboard, glass, and recently also biowaste (primarily green waste from the gardens).

While the Waste Act requires the municipalities to provide collection of also other waste fractions, such as bulky waste, WEEE, or hazardous waste, the comparison of collections of these fractions on municipal level has its issues. Unless the municipality has an HWRC, the collection of these "*additional*" waste fractions is done usually through occasional mobile collections that naturally cost money. Such mobile collection can be notably costly for small municipalities that often cannot even fully utilize the minimum provided capacity of a mobile collection truck. An economic thing to do is then to decrease the frequency of collection of these waste fractions – resulting sometimes in less than once per year optimal collection frequency (which is practically against the legal obligations). Alternatively the municipality can make an agreement with a neighboring municipality that has an HWRC and ask its inhabitants to discard their infrequently collected waste fractions there, either individually or after some "*informal*" agreement among group of them in order to optimize the transport capacities and costs. In both cases is such system incomparable with larger municipalities where the collection of these waste fractions works on a regular basis.

[5] Vyhláška č. 93/2016 Sb., o katalogu odpadu, interactive catalogue available at https://www.katalogodpadu.cz/.

Moreover, certain waste fractions, like WEEE, cloths or some other hazardous waste fractions are sometimes collected by the private subjects (for instance in designated boxes in shops, schools, appropriate public places, etc. or using take-back/discount/refund programs). Such cases create again a distortion among municipalities and direct comparison at the municipal level is then full of various issues and caveats. Due to that I omit quantitative examination of certain waste fractions from the latter analysis and focus only on the main ones.

Expenditures related to MSWM are generally less tricky, although some issues exist here as well. First, we need to distinguish between current and capital expenditures that have been already mentioned in the chapter 1. Current expenditures are those spent on, simply put, day-to-day or other regular activities related to MSWM, like waste collection, waste treatment, and separation – or in other words activities with the waste itself. Capital expenditures are related usually to irregular investments in the field of MSWM, such as the purchase of a new collection truck once the old one broke down, one time purchase of home composters that municipality provides to the households at reduced costs, setting up an HWRC, etc., or let us say an "*infrastructure*" used by the municipality for generally dealing with the municipal waste. Larger municipalities are more likely to have capital expenditures more often, as they administer larger body of infrastructure, while in case of smaller municipalities capital expenditures might occur only once in couple of years.

The next issue is related to the extent at which municipalities provide MSWM. If all municipalities provided MSWM themselves, this would be irrelevant. But in this case we should take into account the concepts of comparative advantages and economies of scale. For a municipality it might be more efficient to contract a professional WM company to secure its MSWM. While one municipality might rely fully on this external company, the second can still take care of some of the WM related activities, while the third can fully secure MSWM on its own. In case of largest municipalities it actually might be, due to the legal issues, the only possible way how to handle their MSWM. It is logical that the first municipality will most likely have little to no capital expenditures, while the second one some, and the third one the highest, even though these municipalities might be providing practically the same level of MSW services to their population. While this might not seem as an issue at first, as in all three cases certain investments have to be made – in case of the third municipality such expenses

come up as capital expenditures, while in case of the first municipality it is up to the external company to deal with this – and the costs from the perspective of the municipality show up as the current expenditure that are reflected in the regular payments for the WM service to the external company. But in practice is this typically not that much of an issue, as large majority of the municipalities use external companies from securing their MSWM, and therefore face more or less the same situation in this area.

In this thesis I focus only on the current MSWE. These expenditures are more likely to be comparable among various municipalities due to the activities they primarily cover – which is waste collection, transport and treatment. While in case of municipalities contracting external company are these expenditures used to pay flat fee per person, per ton or some other agreed sum, in case of municipalities providing MSWM themselves it is used for covering wages, landfill fees, transport, etc. directly. But as the external company has practically the same type of expenditures, current MSWE represent in my opinion a sufficiently comparable measure.

Besides generated waste amount and related expenditures I have collected also several other quantitative municipal data that are in my opinion relevant for MSWM. These include:

Population. Amount of the people living in the municipality is clearly connected with the amount of generated waste and therefore costs as well. The very definition of waste is that it represents the goods that people dispose of – goods that people throw away. The direct link between the amount of the people and the amount of generated waste is then there to be expected. Moreover, it also enables to calculate relative per capita measures, as these are necessary if comparing municipalities of different sizes.

Age structure. In case of age structure I expect that people at different life stages exhibit different waste related behavior. For instance young children are largely affected by their parents, adults that go to work and earn money tend to generate more waste as they consume more, and retired people with limited income behave differently as well.

Other socioeconomic data like unemployment rate, amount of students, or education of the people, that, according to some studies, might have some effect on the waste generation and related costs.

Another often mentioned factor related to the municipal waste management is people's income that is directly connected to the waste-related behavior of the people. The relation is simple – with higher income people are able to buy more, consume more, and as a result produce more waste. Many foreign studies analyze different waste-related behavior of households depending on different income levels. However, in case of the Czech Republic, information about income levels is not available at the municipal level. Although this should be possible from the tax returns or from the data from social security office even at the municipal level, publicly it is not available. I have contacted directly Czech Statistical Office (CZSO) with a question regarding this issue and how they calculate the value of average and median wage. Based on their response, this is calculated using the information from a representative sample and not from actual data from the individual people. With this data CZSO is able to estimate income levels for the whole country, regions, and in some cases the largest municipalities, but it is not possible for individual municipalities.

One way to overcome this issue, which is very common in foreign studies, is to focus only on a small sample, let us say few households or few streets. In this case the researcher can ask the household directly about their income and relate it to their waste generation. However, the size of the sample is in such cases very limited, can practically cover only small areas and the results can only be extrapolated to the whole with a high possibility of bias. Therefore in this thesis I do not include income levels among the factors I analyze, simply because in the Czech Republic this information is not available at the municipal level.

Next group of the data that I have collected are data directly from the municipal representatives of the individual municipalities, as in practice these data are not available anywhere centrally. These data include:

Specific information how MSWM in individual municipality works, how is MSWM provided and what kind of MSWM infrastructure is available in each municipality, both for residual mixed waste and the recyclables. Some elements of local WM are relevant for multiple waste fractions, while some can be specific for one or the other. In case of residual mixed waste, collected information include data on waste collection frequency, whether households have individual or shared waste bins and if there are any incentives related to the household waste generation. In case of recyclables the collected data reflects the available options for waste separation. This includes the prevailing system of waste separation (if any, but in almost all municipalities people have the options for waste separation) – this can be done most commonly by a bring-in scheme or a kerbside collection, frequency of recyclables collection, variety of waste fractions that are collected, presence of any kind of incentives related to the recyclables, etc.

Type of WM company – information whether the company securing MSWM is private, mixed, municipal or publicly owned. Multiple foreign studies examine differences among these companies and come with various results. The question these studies ask is which of these companies provide MSWM the cheapest, or better, or the most efficient – whether the private companies are the most expensive because they focus on profit, or if the private companies are cheapest due to their effort to be efficient or due to the economies of scale. Or if the best company is mixed, because it connects positives of private ownership with the positives of public control, or the opposite, that it brings together the tendency towards inefficiency from public sector and higher costs due to the profit pursuit from the private sector.

Available competition – I have asked municipal representatives about the competitive environment in MSWM in their municipality from their perspective, whether they are able to choose the provider of MSWM, or they practically have to accept the offer from the only one available company. It is then natural that if municipality can choose from multiple offers or has multiple available companies that could provide MSWM, that it is more likely to get a better deal. Another perspective is the bargaining power of the municipality depending on its size. While in case of small municipalities it might not be very profitable for a WM company from greater distance to provide WM services for a single municipality, it is significantly

different in case of the largest municipalities. In those the amount of required WM service creates a greater motivation for the companies even from a far distance to offer MSWM service provision as the possibilities for economies of scale emerge.

Political situation. Finally, I was initially thinking that the political orientation of municipal council and mayor might have some impact on MSWM, but I later have abandoned this idea. In the Czech Republic majority of municipalities are relatively small, with only several hundred people, and do not have a fully professional administrative staff – the mayor is often employed only for a part time while having other regular day job, and this holds usually even more for other municipal representatives. In case of small municipalities the largest problem seems then to be to secure all kinds of obligations that a municipality needs to provide and the differences between the political orientations of individuals often become secondary. The situation in largest municipalities is notably different, with larger council, professional administrative staff containing many people and highest officials focusing primarily on the strategical decisions rather than operative decisions and actions. However, in the ends there are actually only few larger municipalities that could provide some data regarding this aspect, which prohibit from a more reasonable quantitative analysis.

2.3 Data collection process

Data collection process for this thesis can be divided into two, resp. three parts. First group of the data was collected from the databases and involved practically only computer with internet connection. Second group of data regarding MSWM was collected directly from the municipalities by personal visits. Third group of data was collected directly from the municipalities by telephone interviews (and in few occasions also by e-mail correspondence).

I provide a detailed description of the data collection in the municipalities, as it might be of help to others planning to conduct this kind of data collection (not necessarily in the area of MSWM) and they might also benefit from my experience in terms of what to expect, what to be prepared for, and how to plan the data collection process – while it might not seem as that important, when performing a larger scale data collection, mistakes and insufficient planning

can cause a lot of delays or time wastage, which would be, especially with respect to the focus of this thesis, inefficient.

Public databases

The first group of collected data contains statistical information about municipalities and their MSWM. These data include various municipal socioeconomic data, waste generation amounts and related municipal expenditures.

Waste generation related data are provided by the Ministry of the Environment of the Czech Republic (MŽP), specifically at https://isoh.mzp.cz (in Czech only), which stands for Waste management information system (Informační systém odpadového hospodářství). This information system includes modules with aggregated data on waste generation for various waste fractions, registry of authorized subjects in the WM area including addresses of waste related facilities, and more. Most important source of information for this thesis is the module VISOH. This module includes, among others, information about waste generation reported by the Czech municipalities. One issue I have encountered is that the data is publicly provided only at aggregated levels, with the smallest unit of aggregation being area falling under the municipality with extended power (ORP, Obec s rozšířenou působností). There are 216 such municipalities in the Czech Republic, while there are more than 6200 individual municipalities. The organization responsible for this information system, CENIA was kind enough to provide data about waste generation for selected years at the municipal level. With such data, it was possible to conduct further analysis with respect to the individual MSWM.

Municipal solid waste expenditures for individual municipalities are in the Czech Republic publicly available dating back to 2001, respectively 2000. Throughout the years the information systems providing this data changed, but the public availability remained. In all cases the information system was run by the Ministry of Finance of the Czech Republic (MF ČR). Data from 2001-2009 are available in ARIS at http://wwwinfo.mfcr.cz/aris/. Data from 2010-2012 are available in ÚFIS at http://wwwinfo.mfcr.cz/ufis/. From the user's perspective these two information systems are practically same with same available information and same functionality. They provide individual municipal information about expenditures and revenues according to the relevant legislative classification, income statements, balance

sheets, budgets and some other financial information. Some of this information is available also for nonprofit subjects under the municipalities. User can also generate aggregated data sheets for larger administrative units, even for the whole republic, depending on the specific financial report. Generated data can be exported and further processed by a computer.

Same data for 2000-2013 are available also at the site http://www.rozpocetobce.cz, run by a voluntary association, and it provides better options for time comparisons, provides simpler navigation for the common user, is graphically more appealing, and offers possibilities for generating some simple analyses for the selected municipality. Compared to the two previous systems it is much more user friendly, although exporting options are less complex.

Municipal financial data since 2010 are available in information system MONITOR available at http://monitor.statnipokladna.cz/, run by the MF ČR. Most recent available data are usually no older than two calendar quarters and they are reported quarterly for the most recent year and annually for the previous years. Compared to the other mentioned information systems, availability of current quarterly data is a notable benefit. MONITOR offers simple navigation for the user, is quite user friendly and offers possibilities for some time comparisons and analyses of the municipal finance. It is also possible to generate aggregated reports for some larger administrative units than municipalities. From the perspective of this thesis, the most important functionality of this information system is that the visitor can download complete source data used by this information system that contains expenditures and revenues for all individual municipalities and other municipal organization in the Czech Republic in a common data format. This makes is relatively simple, although not trivial, to make further analyses of the municipal financial data. Public availability of such data at the municipal level has a great potential not just for the academic purposes, as it provides practically anyone with the option to analyze selected municipal financial data. While in case of the user interface it might be at first difficult to find some specific data, as the navigation was designed for a common user and often aggregates data from certain fields, in case of the source data it is rather simple for the informed users to quickly find what they seek.

One important note to make here is that one cannot fully rely on the provided data, whether it is the waste generation or the municipal finances. The issue stems from the fact that this data is in most cases reported manually by the responsible person at the municipality. With larger quantity of the data is might happen that the reported value is incorrect, misreported in the wrong/inappropriate/inaccurate category, or missing at all.[6] Reasons for that are insufficient attention by the reporting person, insufficient knowledge of where to report what value (or whether to report it all), or simply insufficient time for data reporting, even though municipalities are obliged to reported this data by the law. Reason behind all this is likely in the size of the municipalities (over 6200 municipalities with median population slightly above 400), as smaller municipalities usually do not have any full-time professional staff, and if, such person has to cover wide variety of tasks in order to provide and secure everything a municipality is supposed to do. In such cases it is then obvious that many activities are prioritized over reporting some statistical data to the central bodies. On the other hand, such errors occur, according to my long-term experience, relatively sporadically and usually can be dealt with by either omitting the municipality from the analysis if the data is missing, or by trimming the dataset from the evident outliers. The fact that the Czech Republic has so many municipalities requires a lot of work with the data, but it also creates a large dataset, where such reduction has only a marginal effect on the final sample.

Socioeconomic data about individual municipalities at annual basis are available from CZSO public database site https://vdb.czso.cz, together with some more detailed and less frequently collected data (namely about housing structure) available in the Census section at https://www.czso.cz/csu/sldb. Census in the Czech Republic occurs every decade, with the last taking place in 2011. CZSO also allows downloading of the majority of the source data in a common electronic format for possible further analyses. Some additional municipal information, or let us say information available in a more user friendly way, can be also found at Regional Information Service site at http://www.risy.cz/cs. However, to my knowledge it does not offer the possibility do download the source data, only viewing them for individual municipalities. On the other hand, it provides some useful thematic maps.

[6] If any doubts about the data arise, one should double-check, for example with the relevant municipality. More on these limitations can be found for instance in Ochrana et al. (2007:30), or Bakoš et al. (2009).

Pilot study

Second group of the data used in this thesis contains information about MSWM in a selected sample of municipalities. The primary research objective of this thesis is to identify and examine the efficiency factors in MSWM. Although there are numerous studies that examine factors that influence MSWM, in my case I did not want just to adopt these factors. Instead of that I have selected specific municipalities from the region, set up meetings with the responsible person for the waste management in a given municipality and visited them in person in order to better understand how MSWM works in the municipalities. I had prepared a list of general questions regarding MSWM that I have asked these people during the interview, together with some questions regarding available waste generation data and related MSWE for the double-check purposes. Nevertheless, majority of the interviews consisted of the explanation of MSWM in the given municipality, how it was run, what kind of system is used, what is working, where are the problems, how are people accepting the system, where the municipality sees further opportunities and so on. The thing is that each municipality is in its own way a unique entity and MSWM in no two municipalities is absolutely similar. In many cases were the provided information about the specifics of MSWM in a given municipalities very interesting and practically impossible to predict unless the responsible person brought them up. Unfortunate fact is that such information in not otherwise available, there is no database of how municipalities specifically provide their MSWM and in each municipality the municipal representatives have to adjust the system to the local unique conditions. The result of these visits were contacts with the responsible municipal representatives, adjustments to the list of factors that are possibly relevant in MSWM and a much better idea about the practical aspects of MSWM in Czech municipalities.

One thing that might distort one's perception of MSWM is that a person usually lives only at several places during the lifetime for a sufficient time in order to get at least some idea how MSWM in that municipality works, if at all. Based on this experience, we are likely to expect that MSWM in other municipalities is more or less the same as in our municipality based on our own limited experience. But this expectation does not hold anymore once you start to examine MSWM in dozens and even hundreds of municipalities with each of them having some unique features and providing MSWM slightly or even notably different. Face to face conversations with the responsible municipal representatives took usually around an hour,

depending on the time limitations from their side and their willingness to share the information on the issue. However, a greater problem was to find a suitable time for the conversations for both sides, as these municipal representatives have to fulfill their regular duties. And finally, as the conversations took place at the given municipality, it took some time to actually get there. All this required careful time planning and necessity to follow often very tight time schedule. Some of the days on which these interviews occurred practically consisted of alternation between half an hour (even up to one hour in case of more remote municipalities) driving to the municipality, some time for preparation for the interview (as the municipal representatives react much better if the interviewer comes prepared and has at least some awareness about the visited municipality) and around one hour of interview with the municipal representatives. This could begin very early in the morning, as from the experience municipal representatives strongly prefer to work from early morning and are often not available anymore later in the afternoon. Moreover, in many cases the municipal representatives are not available every day during the whole working week, as they can have other jobs and other duties. Also, in order to efficiently use available time, I tried to chain multiple municipalities in the same travelling direction – it is not very wise to plan interviews in the municipalities that are hundred or so kilometers apart from each other, one will then spend most of the time by just transporting. Due to the time demand of the interviews, limited availability of the municipal representatives and the necessary time for transport between the municipalities, I was usually not able have more than 3-4 interviews per day – which was, based on the practical experience, rather a solid result, due to the above mentioned issues.

One can ask why I did not choose to perform these interviews over the phone. While theoretically this might seem as a much simpler and more efficient option, in practice it often comes with several issues. From my personal experience municipal representatives are much more willing to share their information once they get proper explanation and reasons for the study plus they have contact with the interviewer. Also many people are not willing to spend hour or so on the phone speaking with a complete stranger that they have never seen and cannot associate with in any way. I have found face to face contact in such kind of situation to work much better, although the drawback in the form of the time demand resulting from transportation is very high. At this stage quality mattered more than quantity.

An important thing related with the interviews was to talk about MSWM with the appropriate person. In my case I firstly always visited the website of the municipality and looked for the information related to the WM, or environment in general. Nowadays majority of municipalities in the Czech Republic have some website, therefore in most cases I was able to acquire at least some basic information about the municipality in the examined area. Municipal website usually provides information about the current municipal representatives, often with direct telephone and e-mail contacts, and if not, at least a general contact to the municipal administration office. In addition to that, municipal office hours are among other things that are mostly available on the website, so I could already suggest appropriate times for the visit with respect to the office hours. Most of these scheduled visits then occurred in the municipal representative's office, but I have also visited a person running municipal waste company at their headquarters, or a person responsible for both MSWM and a landfill within the cadaster in the office directly at the landfill. In all cases I was initially looking for the person officially responsible for MSWM in the given municipality according to the provided information on the website.

These persons were at first contacted with an e-mail describing the purpose of the research and how the research would benefit from the information they could provide. The e-mail also included a part in which I was asking the e-mail recipient to forward the e-mail if it was not addressed to the correct person, which proved useful multiple times. Sometimes the information on the website were not current anymore, sometimes I was not able to clearly identify the correct person (or such information was not provided at all), sometimes the head of the administrative section forwarded it to some other person that was more specialized in the agenda relevant for my research, and sometimes the information on the website were simply too brief and only few main contacts were provided – therefore I had to send the e-mail to the available address and hope, someone will look at it, consider it worth a while and not delete it right away. After some time ranging from hours to few weeks (as some of the recipients were on holidays) I got most of the replies often with direct and working contacts to the correct persons and could start making the arrangements for the personal visits.

From my experience municipal representatives were in most cases surprised that anyone is interested specifically in their work and often initially suspected some commercial offers or

something of that kind. In some cases they also seemed to be rather careful and not willing to tell anything that might be perceived as a negative aspect, perhaps worrying that it might be used against them and possibly even have a later negative effect with respect to their career – as if they already had some experience with getting victimized if they expressed negative opinions about certain things.

This part of the research is often called a pilot study – an initial part of the research where researcher tests data collecting on a smaller scale in order to get some feedback and possibly better understand the examined issue. In order to get more relevant information about MSWM I visited mostly larger municipalities with over 1000 population (27 visits in total), even though majority of the municipalities in the region are less than half this size. But this was later more than balanced during the telephone interviews, where I have contacted by far mostly small municipalities and only very few remaining larger ones. I should note here that the main difference between MSWM in these municipalities is that in a small municipality usually only few (2-3) measures of dealing with the waste are used, while in larger municipality MSWM is much more complex and covers wide array of waste related activities, which actually makes MSWM in larger municipalities much more alike. On contrary, the differences between individual small municipalities in terms of MSWM are in my opinion much greater than in case of the larger ones, even though description of MSWM in a single small municipality is much briefer compared to a larger municipality, as there simply is not that much variety of activities done.

During each of these visits I have taken notes extensively, as these interviews were often full of new information regarding individual municipality's waste management, and if there were multiple visits chained one after another for several days, one cannot simply both remember and distinguish easily between the municipalities. In some cases the interviewed municipal representative could not provide certain additional, mostly statistical information during the time of the visit, and either sent it to me later or I called back to get it at a scheduled time. This was usually a case of the number of drop-off sites for separated waste in case of larger municipalities, development of the waste fee in previous years, amount of collected waste for individual waste fractions or the amount of the expenditure spend on MSWM in the previous years. In some cases the data I had obtained from central databases did not corresponded with

the data provided by the municipal representative, as was already mentioned. However, the deviations were usually only marginal. In such cases I have replaced the data from databases with the data provided by the municipality.

During these visit I also asked the municipal representative about any notable changes in the development of the examined MSWM characteristics, like the amount of the development of the generated waste or MSWE. This part was from my perspective very important, as there is usually no other way how to identify the reasons for the changes than to ask the people right at the source. Some of these observations are discussed later in the qualitative findings subchapter. In one such case I identified a sudden drop in the amount of MSWE without any obvious reason like the decrease in the amount of MSW. After directly asking municipal representative about this observation, the accountant remembered that the WM company forgot to send the invoice for the second half of the year on time, and the municipality paid it in the next year. Without such information directly from the municipality, the municipality would suddenly become among the most efficient, as the amount of waste remained stable with the costs being cut in half. But after taking into account the additional information about the late invoice and subsequent payment, the municipality showed no more dramatic changes between the years.

Telephone interviews

After finishing these visits and collecting some of the missing data that were not provided directly during the personal visits, I have created a set of questions that I distributed in the next stage of the data collection process to the municipal representatives of other municipalities within the South Moravian Region. At first in the form of e-mail and after a rather modest response rate I contacted individual municipalities by the phone, which produced much better results in terms of amount of the collected data. Also by doing this I was able to get immediate response and feedback, I was able to make my points more clear, if necessary, and also got some additional information while talking generally about the current state of W in the examined municipality. Depending on the conditions and willingness of the other side to communicate, such telephone calls lasted mostly between 5-20 minutes, on average about 10 minutes. During this time I introduced myself, explained the purpose and

the objectives of my research and mentioned already sent e-mail (what many of them recalled and sometimes apologized for not replying due to the lack of time or so). In some cases the municipal representative requested to resend the questions instead of answering them directly, as they preferred doing it at their own pace, while many other representatives requested scheduling another telephone sessions due to their other ongoing activities. In majority of cases this rescheduling worked out, and at the next time they had both time and sometimes already some relevant material prepared in advance.

Sometimes, during the initial phone call I was given contact to a different person that was more qualified to answer my questions and later tried to contact him. Also some contacted representatives tried to excuse themselves from the interviews due to the insufficient knowledge about their MSWM, but in many cases I was able to persuade them that majority of questions are easy to answer for almost anyone from the office at a small municipality, which almost always turned out to be true and I was able to get sufficiently qualified answers. The advantage of municipal staff in the small municipalities is that basically everyone knows at least something about everything, so even the accountant or a clerk have sufficient knowledge about MSWM in their municipality from the perspective of my research. And if they did not know the answer to something, they often simply asked their colleague at the next desk for the immediate answer. However, speaking directly with the mayor or vice mayor often had the advantage of providing a broader perspective of the examined issue and connected it with the other aspects of running the municipality. Only in one or two cases during the entire data collection I was directly turned down, as the municipal representative did not was to participate in the research at all without any reasoning whatsoever.

Interesting observation during this data collection was often negative attitude of many municipal representatives towards providing any kind of quantitative data about their MSWM. First of all, such data are in my opinion from their nature public, whether it is the amount of generated waste or the related expenditure. Even according to the Czech information law such information cannot be kept secret. Also many people seemed surprised, once I told them that I am in fact just double checking the data that are already public. Another thing is when looking at this from the perspective of a municipal representative – as being a public subject dealing with the public money, why should it not provide such

information if someone asks for them, especially considering that municipality represents in many aspects a monopoly for providing certain services? Sure, it is understandable that providing such data might require some additional labor, depending on the extent of the request, but still.

In some cases I have identified a notable change in interannual data about the generated waste amount or MSWE. In such cases I have confronted the municipal representatives with this observation and asked them, if they recall anything that might have caused such change. While in many cases they did not provide any answer, as they either did not remember or they did not have a clue, those who recalled something often provided important and interesting answers that one practically cannot acquire by any other means apart from just asking directly. Some of the mentioned reasons can be straightly translated into the factors that notably influence the efficiency of MSWM. For instance a sudden change in MSWE might be caused by the change of the WM company and/or from the new contract. In case of waste generation the reason might be the introduction of green waste collection, new HWRC, other something else. Again, all such changes have one thing in common– unless you have direct contact with the responsible people in the municipality, there is practically no way how to get such knowledge from the centralized databases. Interesting and important findings from these parts of the interviews are included in the subchapter about qualitative findings.

At the end of the interviews I always asked the municipal representatives an open questions about their own observations in MSWM, what they perceive to be working, what should be further improved, what kind of issues they face, what kind of improvement they have implemented or plan to implement and so on. This part of the interview goes beyond the efficiency evaluation, as the answers provided here are very difficult, if at all possible, to transform into the quantitative form for the later analysis. Nevertheless, the very large variety of the answers, full of interesting observations and ideas, provides a valuable source for a more complex understanding of the problems and challenges in the field of MSWM. Many of the mentioned things are the result of very creative thinking of how to deal with the things while taking into the account unique local conditions – but on the other hand, many of them can be generalized and serve as a good (or in some cases bad) example to the other municipalities, that might benefit from the knowledge that something like that can be done,

and that there is already someone that has tried it and some experience with it. It occasionally happened, that while one municipality had for instance creatively dealt with the separated plastics waste fraction by selling it for profit to the nearby factory, another municipality practically on the other side of the hill few kilometers away lamented that they are paying too much to the WM company for dealing with separated plastics. Findings from these parts of the interviews are again included in the qualitative findings subchapter.

The actual collection of the data by telephone interviews took place during most of the summer and part of the fall 2014. It practically consisted of sitting in front of the computer since morning to the late evening, speaking with the municipal representatives and taking notes from their answers. While this might not seem as a difficult task, there were couple issues related with the practical part.

First necessary thing is to make the contact at all. While majority of municipalities have at least some website, information there is not always current. Although it sometimes took some effort to find a correct and working phone number, in almost all cases I was eventually able to make the contact at least with some clerk from in municipality.

The next thing was to contact the appropriate person. If the person I have contacted at first did not have sufficient knowledge about MSWM and could not be persuaded to continue with the interview, like I mentioned before, I was usually given the contact to the responsible person or at least a time window when such person should be available at the office. While this worked in majority of the cases, I have encountered municipalities in which even after multiple calls and rescheduling I was still not able to interview the responsible person, whether it was because the person was always unavailable or did not have time for me.

The thing that turned out to be crucial was to contact the municipality (or at least try to) during the office hours. As majority of the municipalities provide only their landline number on their website, it is in the most cases pointless to try to reach them outside these office hours, as there is simply no one there to answer the phone. This is usually not a problem in

case of larger municipalities with professional full-time staff, but as I have said, majority of the municipalities in the region are small with limited office hours. It was relatively common that some municipalities have office hours only 2-3 times per week for just few hours. And also many municipalities tend to have their office hours at the almost same exact time, thus one cannot schedule the calls that easily, as there are multiple time constraints. In extreme cases the office hours of municipality were just one hour per week or even biweekly. Based on this I eventually created a time schedule of office hours for the remaining municipalities from the sample. Then, at the start of each day during the interviewing phase I have filtered out those municipalities that should have office hours and created a day call plan. Here I stress the word should, as in same cases the office hours of the municipality did not seem to apply according to the provided information, even after repeating the attempts over the course of several weeks.

Due to the observation that many municipalities tend to have limited office hours at the exact same time, after several weeks of interviews I eventually ended up with a bunch of municipalities with office hours condensed into only few time windows during the week. From my experience I can say that the most common municipal office hours occur on Wednesday afternoon and Monday morning, while Tuesdays, Thursdays and Fridays are the least popular. Although it might be surprising, there were actually few municipalities that have their office hours during the weekend. However, the reason is pragmatic – such municipality was most likely including a large recreational area with recreational housings and their count sometimes greatly exceeding the number of permanent housings – thus there was much more people around during the weekends, and it was simply more convenient for these people to meet with the mayor and administrative staff and solve their problems during the weekend and not during the regular working days. This is just one of the examples of how variable the municipalities can be.

Moreover, one has to deal with the things like holiday, especially during the summer, when the responsible municipal representative could not be available for a week or two. In other cases the person with sufficient knowledge about MSWM might be in the office only for few unscheduled hours per week – and during this time this person has to deal with other more important issues than to be interviewed about MSWM for some research purposes. If such

person does not provide personal contact, there simply is no other way how to get the desired information. But even in such cases one has to be prepared that many of these municipal representatives work for municipality only part time, and it might be inappropriate to disturb them outside their office working time.

Next issue to consider is that collecting these data over the phone can be quite physically demanding, at least in the initial phase when there are many municipalities with available office hours. Each of the calls contained up to 20 minutes of talk, followed by approximately the same time for completing the notes, sending further questions that were not answered (usually regarding waste and expenditure statistics) together with my e-mail and phone contacts, or eventually a supplementary information about the research. However, besides the call itself, especially in later stages it proved challenging to find the next available municipality, and thus another 10, 20 or even more minutes could be spend without any successful contact. Altogether, I considered contacting and collecting the data from around 10 municipalities per day to be above average success rate, especially at the later stages of the data collection. As I mentioned, in the final stages of the data collection process I ended up with only few time windows per day with only few municipalities to contact. And if I was not successful, I tried calling another day, or eventually another week. So in the end majority of this process consisted of a lot of time spent on the phone talking to strangers about things you are only partially familiar with. Although the very basics of MSWM are often same in every municipality, each municipality usually has some unique features that should be noted for the possible later utilization. If you contact 10 or even more municipalities per day, it adds up to 2-3 hours of time spent just talking. According to my calculations (and the bill that the university got later, as it was the place where I have made majority of the calls), altogether I have spent more than 100 hours (6000 minutes) just on the phone talking with the municipal representatives, not including the time spent with completing notes, planning calls, doing research about individual municipalities and making further contacts with the municipalities.

Time period of the collected data

Last thing to address here is the period for which I have collected the data. As mentioned before, municipal financial data are available practically since 2001, and since 2010 in a

relatively user friendly form that allows making large set analyses. However, in case of waste generation data, the situation is worse, as I was able to acquire data at the municipal level only for years 2009-2012. In case of socioeconomic data the situation depends on the type of the data. For example, for variables like population is the data easily available for practically every municipality for every year, and there is a high change that such data is correct. But other data like housing structure is not collected on the annual basis and in such cases I had to rely on the most current available data that are from the national census in 2011. With such limited availability of the data I used the 2011 values of certain data as a constant in some of the further analyses, as there simply are no other more current data available. However, in my opinion this in most cases should matter that much, as with data like this I do not expect a large interannual differences in the relatively short period that I was examining.

And finally, in case of the data collected from the municipalities, the latest data are usually from 2013 or 2014. In case of the historical municipal data collection, I have decided not to go further than 2009. The reasons are both that I do not have any older municipal data on waste generation and that from the perspective of the municipal representatives it is already quite far in the past. In many cases the municipal representative simply did not remember details about MSWM from more than 5 years ago, for instance because the personnel has changes after the election, or the person was not responsible for MSWM at that time, or there was a new person employed on the position and thus might not have any knowledge about their MSWM prior to his appointment.

2.4 Data description

In this subchapter I provide description of the data I have collected from the sample of interviewed municipalities together with the explanation of the individual variables. Variables were selected based on initial examination of the overall process of WM in the municipalities during pilot study and based on the typical data used in relevant literature dealing with MSWM efficiency. In the end I was able to make contact with 535 municipalities in the South Moravian Region. Each municipality was identified by its name and a territorial unit number (ZÚJ, základní územní jednotka). List of the collected municipal data includes:

Identification of WM company providing MSWM services in the municipality, including the information about the ownership type of the company (private, public, mixed or municipal), length of the current contract, previous WM company and amount of other potential WM companies that could provide MSWM in order to obtain information about the level of competition in this area. Based on the interview, approximately 25 different WM companies operate in the examined sample of municipalities and include all types of company ownership. Length of the contract varies from more than 20 years to freshly contracted WM companies, depending on the perceived satisfaction of the municipality with the provided WM services and the price for it. In terms of perceived competition, approximately 20% of municipalities suggested only 1 relevant WM company, 20% suggested 2 relevant WM companies, 30% suggested 3 WM companies, 15% suggested 4 WM companies and remaining municipalities suggested 5-9 possible competitors available.

Waste collection frequency, any seasonal changes in the frequency, development of the collection frequency in the previous years, and any differences between different parts of the municipalities. Collection frequency can have significant impact on the overall costs of MSWM. Usually municipalities with less frequent collection are able to lower their MSWE. On the other hand, cooperation of citizens is also important and decreased frequency needs to be accompanied with decreased generation of residual mixed waste in order not to overstock the available capacities of the bins. Depending on the specific municipality, there might be seasonal differences due to the reasons like generation of green waste or a higher turnout of people in case of municipalities with significant amount of seasonal housings. Frequency of collection can also be different for parts of the municipality with single family houses and apartment buildings. Almost 90% of the examined municipalities have on average biweekly collection of MSW. Only few municipalities have less frequent MSW collection. These are typically very small municipalities where it is not economical for the WM company to provide more frequents collection due to the capacity reasons. On the other hand, around 10% of municipalities have average collection frequency under two weeks, usually due to the apartment buildings that require more frequent collection of 1-2 times per week, as the capacity of the provided shared bins is limited.

Waste fee payment development. Most common way to finance MSWM is to collect annual fees from the municipal population. Fee level may vary up to 1000 CZK per capita, as was mentioned in the chapter 2. Majority of the municipalities keep their fee level constant for multiple years, only few make regular adjustments based on the MSWE development or other factors. Most of the municipalities also did not take immediate advantage of increased maximum fee level in 2011 and made mostly only a marginal adjustment to the previous fee level. Besides 5, all examined municipalities use annual fee per capita. Remaining few municipalities charge individual households or houses, or individual waste bins. Approximately 60% of the municipalities charged 450-500 CZK annually per capita, respectively 90% charged 400-600 CZK. There were also few municipalities that did not charge any WM fees and cover MSWE from other sources, but in the Czech conditions this is quite rare. From the other perspective, around 25% of municipalities were able to practically fully cover MSWE from collected waste fees, 20% had to co-finance 5-20% of MSWE, and half of the municipalities had to co-finance 30-50% of MSWE from other sources than fees.

Collection options for recyclable waste fractions. This includes availability of HWRC, drop-off sites, biowaste collection and kerbside collection. Collected information included presence and amount of such options for waste separation and their development. Higher availability of waste separation option should usually lead to increased waste separation and thus reduction in the residual mixed waste generation. This should eventually lead to lower MSWE. 30% of municipalities in the examined sample had some form of HWRC (opening hours varied between every day to once in two weeks, larger municipalities often have multiple HWRCs). Drop-off sites were present in practically every municipalities except 9, were HWRC or kerbside collection was used instead. Biowaste collection availability in municipalities increased from 7% in 2009 to more than 60% in 2014, before it became mandatory for all municipalities in the following year. Around 15% of the municipalities used kerbside collection for waste separation, which is also often mentioned as a very important factor increasing overall waste separation.

Presence of some incentive program. This includes presence of any system that directly influences people's waste related behavior. It can include waste fee discounts based on the amount of separated waste, provision of additional waste bin only for an extra fee (or just

simply making evidence of the amount of existing waste bins in order to check the costs with the WM company), limited amount of the waste bins calculated based on the amount of people living in the house and so on. This was relevant only for approximately 3% of the municipalities in the sample at the time of the data collection, but another 2% were already planning to introduce some kind of motivation. In the recent years is this topic becoming more and more popular among the municipalities, as many early adopters show quite promising results.

Perceived positive and negative aspects of the waste separation, biowaste collection or any other factors relevant for MSWM from the perspective of the municipal representatives, including any additional notes and comments from their side. This final group of collected data represents a very wide group of replies and is described in more detail in the following subchapter.

Table 4 presents basic statistical information about the interviewed sample of municipalities. I provide here data only from 2011, but in the selected subchapters later I use data from other examined years as well. Used databases occasionally did not contain MSW or MSWE values for several municipalities, and thus these municipalities were not included in the calculation of given aggregated values in the table. Therefore only in case of population values the full sample of 535 municipalities was used. I also omitted the largest municipalities in the region from the further analysis. Based on my experience, MSWM in such municipalities is significantly different from MSWM in the smaller municipalities that constitute majority of the sample, and including very large municipalities could create some bias in the results.

Table 4: Basic descriptive statistics about interviewed sample of municipalities, 2011

535 municipalities, 2011	minimum	median	average	maximum
Population	33	557	1 239	34 073
MSW generation per capita (kg)	0.1	210.2	218.5	1 373.4
Total waste generation per capita (kg)	0.4	257.1	247.7	1 672.6
MSWE per capita (CZK)	7.68	538.39	587.47	5 299.69

Source: Own construction using data from CZSO, MONITOR and CENIA

In the later chapters I typically work with smaller subsamples due to the missing, inconsistent, or likely incorrect data in some categories. This was done primarily in order to have a more consistent dataset for the individual analyses that would contain as little as possible incorrect values. In each subsequent case I provide a detailed description statistics about the subsample chosen for the specific analysis.

The issue of incorrect data is a part of the wider group of methodological issues connected with the evaluation of the public finance in general, discussed for instance in Šumpíková et al. (2005:205). Besides incomplete or incorrect data we can sometimes encounter the issue of time inconsistency of the data (typically when the methodology for reporting some indicator changed), changes in the quality aspects that are difficult to capture in the simple numerical form, time lag in the adoption of certain measures, identification of the effects of selected analyzed measures and the definition of baseline for comparison (what would happen if the measure would not be used?), and also the potential alternative use of the finances spent on adoption of the new measure. Such questions are, however, beyond the scope of this thesis.

2.5 Qualitative findings

This subchapter contains additional data and information collected during the interviews with the municipality representatives. However, the nature and often uniqueness of the following data greatly limits them to be used in a quantitative analysis. Nevertheless, I include some of the most interesting ones and discuss them briefly, as some of them might be inspirational for some other municipalities.

Presence of a landfill within the municipal cadaster can have notable impact on MSWM. Such municipalities often greatly benefit from the landfill presence, as they can get access to the landfill services at a great discount or the WM company could make a deal of securing MSWM completely free of charge to the municipality in exchange for the possibility to run the landfill. On top of that, municipality might be able get additional revenues from such company as well. Logically, such municipalities should not be then simply compared with the other municipalities, as their position in terms of MSWM is very much different. However,

with the ongoing trend in EU towards reducing landfills as much as possible, there should be eventually less and less such places.

Distance to the nearest WM company facilities can play a role in a way that WM company in such cases can provide variety of services to the municipality at often very favorable conditions. This is simply because the WM company can "*squeeze*" servicing this municipality between servicing other further municipalities and by doing that better utilize its available capacities. For instance when the garbage truck goes back to the facility and is not full yet, it is almost without any additional costs to pick up some more municipal waste from the close by municipality along the way. Also any occasional demands from the close by municipality can be dealt with practically immediately due to the minimum distance and again with the little costs.

Presence of recreational areas in or close to the municipality can affect the costs of MSWM significantly in case of small municipalities. In larger municipalities this tends to dissolve among the larger population. But in some cases the proportion of the tourists to the permanent population might be very high, and thus additional costs arise. While waste produced by the tourists should actually be treated as a commercial waste by the tourist facilities, it is not always the case, for instance if the tourists use municipal waste bins, that are then reported as MSW, and thus affect MSWE.

Large amount of recreational housings compared to the permanently inhabited ones can also cause issues in MSWM, especially in very small municipalities. For example one municipality in the sample contains 50 houses with 45 of them being recreational. The municipality has only one large shared waste bin which would be on average sufficient, but due to the nature of the dominant recreational housings, waste generation is very irregular, resulting sometimes with overflow of the waste almost immediately after the scheduled pickup, while in other cases is the bin empty even until the next scheduled pickup. Waste generation in such municipalities can depend on factors like holiday, current season or even weekend weather – basically any factor that attracts people to visit their recreational housings. In this specific municipality is, based on the observations of municipal representatives, only

20% of total annual waste generated in the first half of the year, and from the whole waste amount only 40% is generated by the permanent residents and 60% by recreational residents.

Time lags after adopting some waste related measures can also have a significant impact on MSWM. In some municipalities it might take a very long for the new measures to become fully utilized, while in the other people get accustomed almost immediately. An example could be biowaste collection. Some municipalities reported significant change in MSW generation already in the following year after the biowaste collection introduction, while in others it took 3-4 years to have some notable impact. This of course translates also into MSWE. Appropriate communication strategy of the new measures and related information campaigns are often crucial in such cases and can make the difference between successful and fast adoption and an unnecessary wastage of resources (both in terms of time and money) on the other hand.

Littering and illegal dumping is often an issue in many small transiting municipalities, including also those on the state borders. If the neighboring country imposes high fees on the generated MSW, those foreign people might take the risk and dump their waste illegally abroad. While not something done in a larger scale, for those few small municipalities it can cause a notable pressure on the budget, as dealing with illegal dumping is usually quite costly. A similar problem with illegal waste dumping in the form of littering can happen in municipalities with some important transport corridor in their cadaster. Trespassers can simply stop by along the road and produce some waste, leaving it on the spot. And if others see it, it often does not take a long time before small illegal dumps emerge. Another example of the impact of trespassing people was from municipality that had installed 2 large shared containers in addition to the regular individual waste bins. These containers were installed next to the main road crossing in the municipality. It always took relatively short time before these containers were filled up, primarily by the trespassers. Municipality then had to frequently order pickups from the WM company for the additional costs. But once the municipality moved these 2 containers to a less visible place for the trespassers (but still easily accessible for the locals), total waste generation of the municipality decreased by notable 35%.

Municipalities with new housings can face the problem that incomers already require WM services but do not pay the full fees as they do not have permanent residency there. Analogous problem occurs in the largest municipalities where people come to work or study, but again do not have a permanent residency there. MSWE in such municipalities are then higher, while the collected fees do not increase accordingly.

Geographical conditions can have an impact as well. A remote municipality has often very few choices of WM companies and usually has to accept otherwise less favorable offers in order to have at least some WM services provided. Rough terrain can also become an issue for more efficient waste collection using larger trucks. In winter it might even prohibit waste collection from the remote parts or municipalities at all and several such municipalities thus provide only centralized bins for their inhabitants.

Gasification of the municipality can cause a great decrease of the generated MSW, once people no longer use fossil fuels for heating and discard subsequent burned waste together with mixed residual waste. For this reason, in the municipalities without gasification one can often identify notably increased waste generation during the heating season in winter (especially if the winter is colder), while in majority of the municipalities is the waste generation during winter typically lower, with the reason being little to no green waste generation during this period.

The way how the WM company counts the collected waste can have impact on the final MSWE. This is usually not an issue in larger municipalities that can fill up whole or multiple garbage trucks, but it might become important for small municipalities from which the truck collects waste in a sequence. If there is no scale installed on the truck, it might be unfavorable for some while favorable for other municipalities, as the amount of waste assigned to individual municipalities depends on the judgement of the WM employer or the truck operator. Especially in very small municipalities this can cause a notable distortion of the data.

Anonymity in larger municipalities, especially among people living in apartment buildings, can lead to the worse waste separation and more mess around waste bins, which requires additional costs from the municipality. In smaller municipalities such inferior behavior is much less frequent.

A municipality can try to sell separated waste on its own at the market and earn additional revenue this way. In one case a municipality rented a machine for construction waste processing and then sold the product on the market. Costs per processing one ton of such waste were 100, while selling price was 500, showing that proper MSWM can provide the municipality with the opportunities for additional revenues and not include just the costs.

A municipality can provide some parts of MSWM using its own capacities, for instance using municipal employees or unemployed citizens.

In some municipalities some **people might still prefer burning their waste or dumping it illegally** in the woods instead of discarding it to the designated waste bins, even if they have already paid their waste fee. But according to several municipal representatives, sometimes people just do not want to give up their old habits. One municipality dealt with such illegal dumping by installing warning signs in the usual waste dumping areas saying that these areas are under surveillance. Even if there was no camera installed, problems with illegal dumping soon practically disappeared.

A municipality can have **an agreement with the neighboring municipality** that its people can use drop-off sites and HWRC in that neighboring municipality free of charge. This might result in distorted observations, as one municipality shows less separated waste while the other shows more. An even larger distortion can happen in municipalities with few permanent residents and a lot of recreational housings. Per capita residual and separated generation of waste calculated using the number of permanent residents produces logically very high values in such cases.

Personal involvement of the municipal representative (usually mayor or his deputy) can make a big difference in MSWM, especially if this person is willing to try new progressive things in WM and is willing to devote sufficient time into communicating the benefits of the new measures to the citizens. Professional education of the municipal representative in the WM field can improve this even more.

Biowaste collection has great potential in some municipalities. There were reports that after introducing biowaste collection, MSW generation decreased by up to 50% together with the MSWE decrease by 40%. Presence of local farmers willing to utilize collected biowaste can result in additional revenues for the municipality, while lowering the costs for the biowaste treatment and collection, as the farmers can take care of this waste by themselves.

The quality of MSWM services provided by the WM company can vary notably and simple fact that one company is more expensive might not mean that it is actually worse for the municipality. Services from a more expensive WM company can, for example, include higher frequency of waste collection, more flexible reactions should some waste overstocks happen, better response time if some other related issues occur, provision of additional extra services, etc.

And finally, probably the most important thing affecting WM in individual municipalities is **the behavior of the people**. Persuading people to cooperate correctly with the current waste system in the municipality and to follow the given rules represents the greatest opportunities in improving the performance of MSWM.

3 EFFICIENCY EVALUATION IN THE MUNICIPAL SOLID WASTE MANAGEMENT[7]

This chapter contains efficiency analysis in order to identify the potential factors of efficiency that are examined more thoroughly in the following chapter 4.

3.1 Sample description

I conduct this efficiency analysis on a sample of municipalities from South Moravian Region in the Czech Republic. Municipalities in the Czech Republic are rather scattered with a lot of small independent municipalities. This has an advantage of a possibility to acquire a large set of data, but it has also a drawback that the data gathering becomes often difficult and time consuming, unless the data is centrally provided. South Moravian Region consists of almost 700 municipalities with total population of almost 1.2 million with regional capital Brno (population 380 000). Besides Brno there are no other larger municipalities with second largest Břeclav having population of 60 000. Nevertheless, due to the significant difference in the size compared to the rest of the sample, I exclude these largest municipalities. I have collected general data regarding population and housing structure from CZSO, data regarding municipal expenditure were collected from MF ČR, and data regarding the generation of municipal waste were acquired from CENIA. These characteristics are often used in the researches regarding MSWM efficiency. For additional data about MSWM-related infrastructure (in many studies identified as a very important factors affecting MSWM efficiency) I have contacted majority of the municipalities in the region by either e-mail or telephone call. However, some municipalities provided insufficient data, and thus were removed from the sample. Finally I have excluded several municipalities for which I have acquired obviously incorrect data from either MF ČR or CENIA (typically extremely low amounts of expenditure or generated waste caused most likely by incorrect data reporting). After these adjustments I ended up with sufficient data for a sample of 463 municipalities.

Table 5 shows that majority of municipalities in the sample are relatively small, which is common in the Czech Republic. Almost three quarters of municipalities in the sample have population of less than 1000 with slightly more than 300 separate dwellings. I include share of

[7] This chapter includes parts from Struk (2015a)

the condominium dwellings on the total amount of dwellings, as this has been suggested by the municipal representatives as one of the factors having an impact on the overall state of MSWM. In addition I include the ratio of dwellings used for recreational purposes to the regular dwellings, as this has been also suggested as another important factor in MSWM, especially if this ratio is high (I do not provide a share from the total dwellings, as recreational dwellings generally do not count towards regular dwellings, and therefore it is possible for a municipality to have more recreational dwellings than total regular dwellings). Further descriptive statistics about the selected data of the sample follow. Individual columns show data for sorted municipalities at each quarter of the sample plus the average value.

Table 5: Descriptive statistics of the analyzed sample of 463 municipalities by quartiles

	Q0	Q1	Q2	Q3	Q4	Average
Population	36	305	589	1036	34 073	1 083
Dwellings	14	109	198.5	339	13 813	381
Condominium share	0.0%	0.0%	4.9%	10.2%	89.7%	8.2%
Recreational ratio	0.0%	1.6%	5.3%	13.2%	215%	10.2%
Built-up area (ha)	1.5	7.2	11.7	18.3	281.8	16.93
Density (per ha)	8.9	40.0	51.4	64.5	202.8	53.6
Drop-off sites	0	2	3	5	145	4.9
Population/drop-off site	0	130	195	287	1 412	234
MSWE (000 CZK)	21	165	319	587	34 799	660
Separated waste (t)	0	19	46	110	5179	135
Separated waste share	0.0%	20.4%	29.4%	38.7%	70.1%	29.8%

Source: CZSO, MONITOR, ISOH, own research

Considering the data about the generated municipal waste, I note that as separated waste I take into account the standard types of wastes that are usually collected at drop-off sites and HWRCs: paper and cardboard, plastics, glass, WEEE, metals, biodegradable waste (typically garden waste), and bulky waste[8]. Together with MSW I consider all this waste as the total municipal waste. Commercial waste was not taken into account here, as this research is aimed solely on municipal waste. Also, as was mentioned in the beginning, according to the Czech law, commercial subjects are responsible for dealing with their own waste, and thus municipality is not involved in this process and should not have any related expenditures.

Besides characteristics included in Table 5 I have collected data about the MSW collection

[8] I exclude hazardous and remaining minor types of wastes generated in the municipalities, as these are not regularly collected by municipalities or in all HWRCs. However, this should not matter much as these kinds of wastes attribute for a very small fraction of total municipal waste, thus creating rather insignificant distortion in the data.

frequency. In few municipalities there are instead of regular bins few large containers in the center of the municipality (these are usually very small municipalities with geographical situation that does not allow for a regular door-to-door collection). In such cases is the container emptied when it is full, what happens on average once every 2-3 months. On the opposite side are usually the largest municipalities that have weekly collection of MSW, and in cases of areas consisting mainly of apartment buildings with larger bins for multiple dwellings is the collection frequency even twice or more per week. On average, the collection frequency of MSW in the sample is 2.2 times per month.

Next I have collected information about HWRC opening days per week. Slightly over one quarter of municipalities in the sample have an HWRC (including also those unofficial ones, but in fact offering roughly standard HWRC services). Opening days per week span from 0.25 (open once per month) in the very small municipalities up to 6 times per week in the largest municipalities (where there are usually multiple HWRCs as well). The average amount of opening days of HWRC (if at least some variation of HWRC is present) is 2.2 times per week.

Additionally I have collected information about several characteristics that generally have impact on the efficiency of MSWM and can be represented in the binary form. These include information whether people in the municipality have an option to dispose of their waste in a HWRC free of charge (either HWRC within their municipality or some neighbor municipality that agrees with such disposal, usually as a part of an intermunicipal cooperation), information whether municipality makes some kind of waste bin evidence (usually by issuing yearly stickers, stamps or barcode stickers), information about the presence of some incentive program (typically providing discounts based on the amount of separated waste by individual dwellings participating in the program), information whether municipality provides some kind of kerbside collection of recyclables, and information whether some kind of collection of green garden waste was available to the people in the municipality.

3.2 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is, according to Ramanathan (2003:25), a methodology based upon an interesting application of linear programming. It was originally developed for

the performance measurement and has been successfully employed for assessing the relative performance of a set of firms (or alternative units) that use a variety of identical inputs to produce a variety of identical outputs.

DEA utilizes techniques such as mathematical programming which can handle large numbers of variables and relations (constrains) and this relaxes the requirements that are often encountered when one is limited to choosing only few inputs and outputs because the techniques employed will otherwise encounter difficulties. Relaxing conditions on the number of candidates to be used in calculating the desired evaluation measures makes it easier to deal with complex problems and to deal with other considerations that are likely to be confronted in many managerial and social policy contexts (Cooper et al., 2006:2).

And finally the last two definitions: DEA is a nonparametric, mathematical programming-based technique for efficiency measurement (Thanassoulis et al., 2008:251), and DEA is a nonparametric method of measuring the efficiency of a decision-making unit (DMU) such as firm or a public sector agency (Ray, 2004:1). With this basic idea of what is DEA about we can move to its historical background and principles.

History

Building upon the foundations set by Koopmans (1951), Debreu (1951) and Farrell (1957), a technique that later became known as Data Envelopment Analysis was introduced into the Operations Research field by Charnes, Cooper and Rhodes in 1978. Their original CCR model (named after their surnames) was applicable to technologies with constant returns to scale (CRS), which was somewhat limiting. However, after few years a major breakthrough occurred, as Banker, Charnes and Cooper (1984) extended their original model into BCC model which was able to accommodate technologies with variable returns to scale (VRS) (Ray, 2004:1).

In the following years DEA usage experienced a boom as it became a valid alternative to regression analysis for the efficiency measures. Relevant literature on either theoretical

aspects of DEA, as well as various practical applications, began to grow exponentially in 1990s and 2000s. Popularity of the DEA technique grew along with the development of software tools for its solving. As DEA consists of solving linear programming problems, with increasing numbers of DMUs and considered inputs and outputs, the actual computing became very time-consuming while requiring a lot of precise procedures. But with the appropriate software, solving DEA problems became much less demanding in terms of computation, and thus making this method very popular. A list of the programs solving DEA problems is provided later.

The popularity of DEA can be illustrated by the amount of the published literature dealing with the topic. For instance Ray (2004:1) states than in 1992 there was almost 500 publications dealing somehow with DEA, while in 2002 there was already more than 3 000 DEA related publications. According to the search in Web of Science, in 2012 there was almost 6 000 references, while Google Scholar returned more than 40 000 items when searching for Data Envelopment Analysis. Recently in 2018 Google Scholar returned over 260 000 results, illustrating the popularity of this method, even though notable portion of the results might be just mentioning DEA in the text and not be directly dealing with DEA. Table 6 shows development of DEA papers in WOS and Scopus databases in 2004-17 period.

Table 6: Published DEA-related papers indexed in Web of Science and Scopus, 2004-17

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
WOS	240	272	313	372	480	690	691	787	780	838	962	1165	1202	1271
Scopus	298	353	429	476	634	952	985	1045	1066	1165	1214	1093	1204	1357

Source: own construction using WOS and Scopus

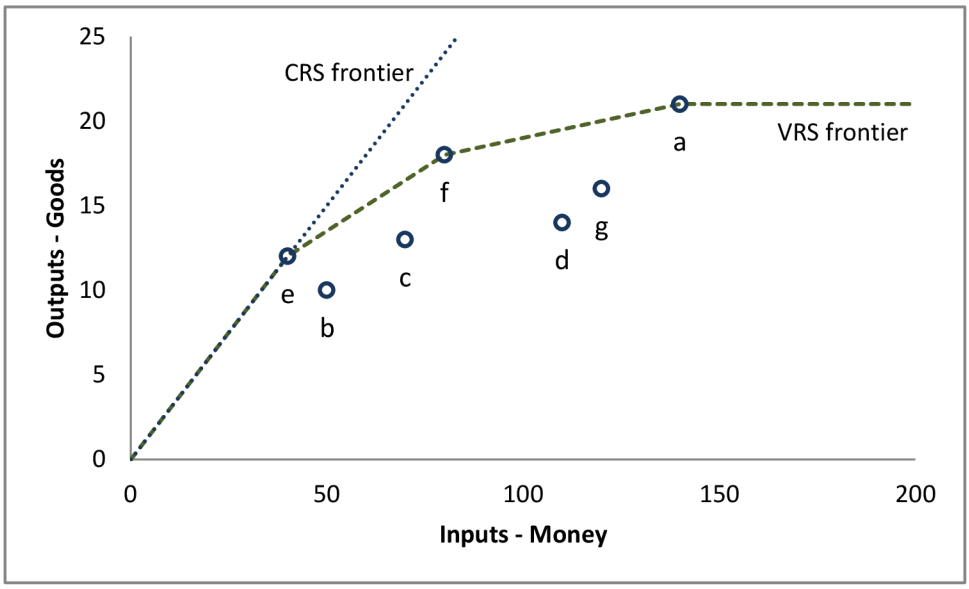
Very good explanation of the DEA history prior to its "*reanimation*" by Charnes, Cooper and Rhodes (1978) is available from Førsund and Sarafoglou (2002) in their study "*On the Origins of Data Envelopment Analysis*". This study covers thirty years of the related development in the field of economics since Farrell's paper (and accompanying discussion) in 1957, and elaborates the connection between the two.

Next thirty years of DEA development after the CCR publication in 1978 is described by Cook and Seiford (2009). Their paper focuses on the methodological developments while omitting the practical applications that appeared during the period.

Principles

The basic idea behind DEA is the creation of an "*efficiency frontier*" by the units with the best output-input ratios[9]. According to Ramanathan (2003:25), "*DEA is a linear programming-based technique for measuring the performance efficiency of organizational units which are termed Decision-Making Units (DMUs). This technique aims to measure how efficiently a DMU uses the resources available to generate a set of outputs*". The basic efficiency measure of DEA is the ratio of total outputs to total inputs. Important note is the fact that efficiency is evaluated only within the units from analyzed set and thus results cannot be generalized for the units outside the set. Figure 10 illustrates a simple DEA example with both constant returns to scale and variable returns to scale.

Figure 10: Example of CRS and VRS efficiency frontier, case with 7 DMUs, 1 output, 1 input



Source: own construction

Figure 10 provides a situation with 7 DMUs (marked "*a-g*"), with each of them consuming certain amount of inputs – money, and producing certain amount of outputs – goods. DMU

[9] Such methods as DEA or SFA are sometimes called „*frontier*" or "*distance*" methods.

"*e*" is clearly the most efficient yielding highest output to input ratio. Together with point "*0,0*" it forms constant returns to scale (CRS) efficiency frontier while points "*0,0*", "*e*", "*f*" and "*a*" form variable returns to scale (VRS) efficiency frontier.[10] In this example (one input, one output) the visualization in simple, but with more inputs and outputs are the results of the models usually presented only in numerical form.

DEA method, through linear programming, provides a way of how multiple inputs and outputs can be *"stacked"* together in order to create one total output and one total input (through assorting appropriate weights for each partial input and output), so that the relevant efficiency ratios can be computed for each DMU. After that, the *"most"* efficient units (usually called peers) are identified and get efficiency score of 1 (unity). Other DMUs that do not lie on the efficiency frontier get efficiency score other than 1 depending on their distance from the closest efficiency frontier constituted by one or two peers.[11] These different scores tell how the inputs or alternatively outputs (depending on the DEA model specifications) need to change in order to make inefficient DMU efficient (so that its position moves to the efficiency frontier) and are called *"slacks"*.

When calculating DMUs efficiency scores, λ-values are used. Together with the efficiency score they provide information about the actual position of examined DMU in respect to its peers. Based on the linear programming, λ-values tell to what extent was the peer used in order to construct a vector on which examined DMU lies. And the efficiency score simply tells where on this vector the DMU is situated with 1 meaning it is right on the efficiency frontier formed by the peers and values less than 1 meaning the distance from this efficiency frontier.

[10] Here can be seen the analogy with the concept of production possibility frontier from microeconomic theory – area under the efficiency frontier is the production possibility set, however, only results on the frontier are considered efficient. DEA can be, in certain aspect, seen as a "*reverse process*" of production function analysis.

[11] An inefficient DMU can get efficiency score either above or below one, depending on what exact type of model is computed. However, scores are reciprocal and thus tell the same information about the distance from the frontier.

Formally, an input-oriented measure of technical efficiency of the DMU t in the sample of N DMUs with input vectors x_j and output vectors y_j, $(j = 1, \dots, N)$ is then obtained from the following linear program:

$$\min \theta \,, s.t.$$

$$\sum_{j=1}^{N} \lambda_j \, x_j \leq \theta x_t,$$

$$\sum_{j=1}^{N} \lambda_j \, y_j \geq y_t,$$

$$\sum_{j=1}^{N} \lambda_j = 1,$$

$$\lambda_j \geq 0, j = 1, \dots, N$$

Then we can define $x_t^* = \sum_{j=1}^{N} x_j \; \lambda_j^* = \theta^* x_t$ for the optimal value of objective function θ^* and optimal multipliers λ_j^*, $j = 1, \dots, N$. Then (x_t^*, y_t) is the efficient input-oriented projection of $(x_{t,} y_t)$ and its technical efficiency is defined by $eff(x_{t,} y_t) = \theta^*$ (Struk and Matulová, 2016).

Førsund (2018) provides an accessible economic interpretation of DEA. Further explanation of mathematical programming aspects of DEA together with the theory behind DEA can be found in DEA textbooks, for example Ramanathan (2003) or in Czech in Jablonský and Dlouhý (2004, 2015), and also in more comprehensive books like Cooper et al., (2006), Fried et al., (2008), or Ray (2004). This thesis does not intend to describe the computational aspects of DEA and for such the reader should refer to the provided literature.

Intuitively, as was already mentioned, with more inputs and outputs, as well as amount of DMUs, the computation of DEA results becomes increasingly time-demanding. However, the results of DEA are in practice usually calculated using some available DEA-solving programs or spreadsheet extensions and thus the researcher performing efficiency evaluation is not limited by these computational aspects. A good list of available software for solving DEA

problems can be found at webpages www.gapem.org/default.php?ref=papers and www.opendea.de/verfuegbaredea.php.[12] Selected DEA solving programs are listed in Table 4.

Although presented list in the Table 7 contains many options, it is necessary to note that some of the programs are commercial and require a purchase in order to be utilized. On the other hand, there are still free of charge opportunities for DEA problems solving, especially if problems do not contain large datasets (as some of the commercial programs offer free demo versions with limited number of DMUs, inputs and outputs).

Table 7: List of DEA solving programs

Program	Author
DEA-Excel	Jablonský, 2008
Deafrontier	Zhu, 2003
D.E.A.O.S.	Int. Institute of Operations
DEAP	Coelli, 1996
DEAQual	Kamakura
DEA Solver Online	Uni. Hohenheim
DEA Solver Pro	Saitech
EMS	Uni. Dortmund
FEAR	Wilson, 2008
Frontier Analyst	Banxia
GAMS/DEA	Gams
iDEAs	Keck Virtual Factory Lab
ISYDS (SIAD)	Angula-Meza et al., 2005
KonSi DEA Analysis	Konsi
LIMDEP	Limdep
MDeap	Deslierres
myDEA	Wilken, Harren
OnFront	Emq
PIM-DEAsoft	Deasoftware.co.uk
Qhull	Uni. Minnesota
xIDEA	Prodtools
Warwick DEA software	Uni. Warwick
Win4DEAP	Deslierres

Source: gapem.org, opendea.de, nb.vse.cz/~jablon/

When making actual calculation, the only necessary thing with available programs is to have the data. Some of the programs require specific format of the data, while other allow direct

[12] Both sites are unavailable at the time of the writing of this thesis. Fortunately, they can be still accessed using Wayback Machine at web.archive.org/web/20101219151559/http://www.gapem.org/default.php?ref=papers, and web.archive.org/web/20160403085152/http://opendea.de/index.php/verfuegbaredea.

input of the data. After that there are usually some options regarding the formulation of the desired DEA model, nevertheless, even without the deeper knowledge of the DEA theory one can choose basic ones and acquire results that should be relatively easy to interpret. Some of the programs would even produce a graphic output and some other additional information concerning examined DMUs and the dataset.

Pros and Cons

DEA has several advantages as well as some disadvantages. The most notable advantage is probably the ability to handle multiple inputs and outputs that can be expressed in various means. This becomes especially useful when dealing with decisions in a complex environment. Among other advantages is, for example, no need for a specified production function, as DEA "*constructs*" the production frontier from the available data, DEA's ability to uncover relationships that might not be clear to see, or the fact that one can analyze and quantify the sources of inefficiency for every unit from the set. Another advantage implied by the previous one is the unnecessary presence of money, which can be very useful when conducting analyses in the public sector where unmonetized inputs and outputs are often likely to occur.

However, DEA has limitations too. The main of them is the choice of the inputs and outputs that enter the evaluation (as some important ones can be omitted and thus the analysis would yield incorrect results). Also the choice of the evaluated units is an important factor, as DEA evaluates only the units within the analyzed set and the results cannot be simply generalized for the whole population. A single one new unit can notably change the efficiency of the rest of the sample. On the other hand, this is more likely to be a defining feature that emerges from the principles of this method rather than a disadvantage in its exact nature. Also units lying outside the cone formed by efficiency units can be sometimes still considered as efficient. More about this can be found in already mentioned textbooks on the DEA topic like Ramanathan (2003), or Cooper et al., (2006).

Moreover, as DEA is a nonparametric method, there is no production, cost or profit function estimated from the data. This leaves a rather very limited possibility for evaluating marginal

products, partial elasticities, marginal costs, or elasticities of substitution from a fitted model. This prevents the usual conclusions about the technology, which is possible from parametric functional form (Ray, 2004:2).

And finally, as DEA is of nonstatistical nature, the solutions to the problems by linear programming produce no standard errors and leave no room for hypothesis testing. With DEA any deviation from the calculated efficiency frontier is treated as inefficiency, rejecting any random shocks (Ray, 2004:2). Lack of standard errors in DEA efficiency measures stems from the fact that stochastic properties of inequality-constrained estimators are not well established in the econometric literature. Even with simple DEA problems this becomes a very complex issue, and, according to Ray (2004:5), the solution is unlikely to arise in near future, although there are several lines of research addressing this problem.

Fields of Research

When it comes to the bibliography, there are several comprehensive studies that list the development of publications concerning DEA right from the very beginnings.

Emrouznejad's web page dedicated to DEA, http://deazone.com, can serve as a good source for papers containing practical DEA results and discussing its various aspects. Besides provided references to several thousands of DEA studies, Emrouznejad et al. (2008) had published selected statistics about the DEA literature covering roughly 30 years after the initial CCR study, together with the recently updated study of first 40 years of scholarly literature in DEA (Emrouznejad and Yang, 2018).

Another very comprehensive study comes from Gattoufi et al. (2004b), who published a 70-pages long list of DEA-related studies, including 13 studies prior to the CCR publication in 1978 that are, according to Førsund and Sarafoglou (2002), related to the DEA concept. This list contains more than 1 800 studies, dissertations, proceedings or book chapters up to 2001. Along with that, Gattoufi et al. (2004a) have published another study about the *"taxonomy for data envelopment analysis"*, where they present a scheme for classifying DEA literature

according to several criteria. Just to illustrate the popularity of DEA, Seiford in his *"Cyber-Bibliography"* from 2005 lists 2800 DEA-related studies, which means about 1000 publications increase in four years when compared with Gattoufi et al. (2004b).

When it comes to the real-world areas of DEA focus, the ideal applications include areas where there are many DMUs that use comparable inputs and produce comparable outputs. For instance, some notable publications in the field of environment are Coli et al., (2010) who have evaluated environmental efficiency of Italian provinces; Honma (2014) who evaluated eco-efficiency of 31 Asia-Pacific countries and regions; Korhonen and Luptacik (2004) who evaluated eco-efficiency of power plants; or Kuosmanen and Kortelainen (2005) who evaluated eco-efficiency of road transportation in selected Finnish towns. In the other areas related to this thesis, public services, selected notable publications are Afonso and Fernandes (2008) who created comprehensive comparison of local government efficiency using the data for Portuguese municipalities; Kirkpatrick et al., (2006) who used DEA to compare efficiency of state and private sector provision of water services in Africa; or Woodbury and Dollery (2004) who examined municipal water services in Australia. Here, one can easily see that DEA is especially popular for analyzing network industries. This list is by no means exhaustive and rather reflects the research focus of the thesis. Numerous other applications of DEA can be found in banking, seaports or agriculture sectors.

3.3 DEA evaluation of efficiency

I use Two-stage DEA (2SDEA) for the efficiency analysis, first introduced by Ray (1988). 2SDEA represents an extension to the standard DEA by adding a regression analysis of the computed efficiency scores of units on other relevant variables. Adding a regression in the second stage also overcomes one of the pitfalls in the DEA methodology discussed by Dyson et al. (2001) – an assumption that all units within the sample operate in the same environment. However, some limitations of this methodology still exist, as noted by Simar and Wilson (2011). Nevertheless, the primary advantage of employing 2SDEA is that it can both point out which units perform the best and suggest what might cause it. Depending on the nature of such identified factors, other units might be able to adopt them in order to increase their own efficiency. Hoff (2007) provides further discussion of approaches used in the second stage of

DEA. Liu et al. (2013) conclude that two-step DEA became a prevailing approach in recent years, what is in my opinion natural, as knowing what makes units efficient is in my perspective even more important than just knowing which of them are efficient. 2SDEA has already been used for measuring efficiency in the sector of municipal waste management, for instance by García-Sánchez (2008) in Spain, Marques and Simões (2009) in Portugal, or De Jaeger et al. (2011) in Belgium.

First stage of this method consists of calculating the efficiency of decision making units (municipalities) using DEA. By doing this each municipality gets a score between 0 and 1 depending on the levels of inputs and outputs. In some studies this is the final result as well, as the efficient units are identified together with the estimation of how much can they improve in order to become efficient and therefore acquiring the efficiency score of 1. With 2SDEA I extend this and use the calculated efficiency scores in a subsequent regression analysis with various characteristics of MSWM in order to explore the possible effects of these additional characteristics on MSWM efficiency.

I provide two models regarding the DEA calculation. Here I simplify the whole process of MSWM into a black box where on one side we insert the amount of MSWE (inputs) and on the other side we get certain amount of served units of population or dwelling (outputs). It is possible to consider this process the other way round, but the results would be the same – we either consider that efficient municipalities are those with more outputs for the expenditure, or those with less expenditure in order to serve the initially inputted amounts of population, dwelling, etc. I assume the one and only input to be the amount of MSWE, as I perceive it as the resource that is inputted into MSWM. While some studies like García-Sánchez (2008) use multiple inputs like staff, vehicles and containers, in my opinion it can be simplified to the one input in the form of expenditure. Mentioned inputs can be then purchased and it is up to the DMU (or in this case waste management service provider) to create a best mix depending on the perceived marginal productivity of each of such production factors. Moreover, due to the nature of our sample, I do not expect significant differences between the costs of the production factors between waste management providers, therefore a common input in the form of expenditures seems as appropriate. On the other side of the process, or as outputs, I put the amount of municipal population, amount of dwelling within the municipality and the

size of built-up area served by MSWM. I perceive these three parameters as the output of the whole process of MSWM. Such input-output specification of the DEA model is comparable with for instance Rogge and De Jaeger (2013).

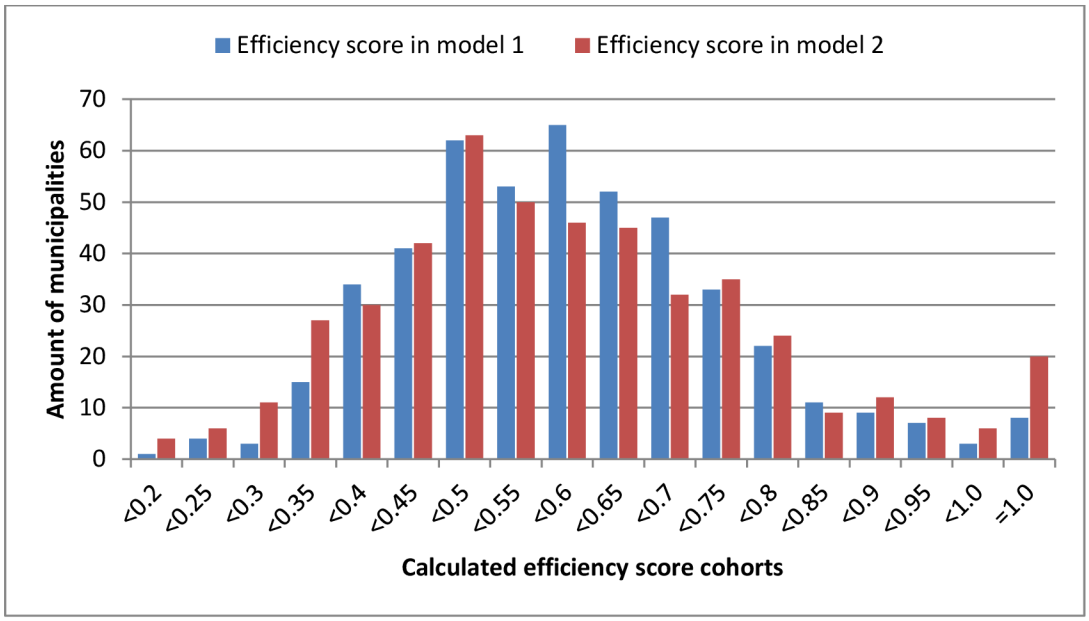
DEA offers a possibility to choose from various models depending on the exact thing one is exploring. In this case I use one of the most common models developed by BCC, which extends the basic CCR model by allowing variable returns to scale. I use this model instead of the basic CCR one due to the large variance in the size of the municipalities I analyze. As the size of the municipalities in terms of population spans from several dozen up to several thousands, I assume that there is not some constant effect with increasing size, but rather some variability in the scale effect throughout the sample. Furthermore I set the model to be output oriented, meaning that given the "*fixed*" amount of expenditure I consider the municipality to be more efficient if it is able to produce more outputs, in this case to provide MSWM to more people, dwellings, larger area (efficiency model 1), and additionally produce more separated waste and have higher share of separated waste to MSW (efficiency model 2). An alternative interpretation would be that the more efficient units (municipalities) are those with less expenditure given the "*fixed*" amounts of outputs.

Therefore the first efficiency model has 1 input (MSWE) and 3 outputs (population, dwellings and built-up area). Second efficiency model has additional 2 outputs (amount of generated separated waste and share of separated waste on the total municipal waste), resulting in more stress towards the factors directly related to the waste separation, when compared to the first model. In these models I specifically do not include total amount of collected residual waste, unlike in many studies, as in my opinion in such cases the efficiency could possibly go the opposite than desired direction – a more efficient municipality would be the one that is generating more waste for the fixed amount of costs, which I do not perceive as a desired result, at least from the environmental perspective, even though strictly economically speaking it makes sense.

Both models have been calculated with OSDEA software. In the first model 8 efficient units (also called peers, or the units with 100% efficiency) were identified, while in the second

model 20 units were identified as efficient (all efficient units from first model were included). Increased number of efficient units is the usual consequence of adding more inputs/outputs, as we are dealing with a more dimensional optimization problem. Following Figure 11 shows the distribution of acquired efficiency scores among the units in the sample.

Figure 11: Frequency distribution of calculated efficiency scores of municipalities



Source: own calculations

Regarding the efficient municipalities, they are relatively diverse with no significant features that only they would have, compared to the rest of the sample. There are both larger and small municipalities, they have various waste collection frequency, only half of them have HWRC, one third has adopted kerbside collection, their expenditure per capita are about the same as the rest of the sample, so there is no clear direct connection between the presence of some factor and a high level of acquired efficiency score. The only thing they have in common is a significantly higher than the average generation of separated waste per capita, together with higher than average share of separated waste on the total generated municipal waste.

Factors influencing efficiency

In the second stage of DEA I used calculated efficiency scores as the dependent variables in the subsequent regression analysis using simple OLS technique for estimating effects of the independent variables. As the potential independent variables I chose various characteristics

of MSWM, with each of them practically creating own hypothesis regarding the effect of this factor on the MSWM efficiency. Used characteristics were chosen based on the availability of the data collected from the municipalities and those available from public databases. The limitation here is that some important influencing variable might have been omitted, and the results could thus be biased, but this is a feature of such model and it is up to researcher to try to specify the model to the best of his knowledge and the availability of the data. I need to note here that the exact values of the coefficients are not that important as they are related to the constructed efficiency score. More important is the trend suggested by the calculations and the significance of the effect compared to the other variables. Results of the calculations are provided in the Table 8.

Table 8: Effects of selected MSWM characteristics on MSWM efficiency

Effects of selected MSWM characteristics on the efficiency (in %)	Efficiency model 1	Efficiency model 2
MSW collection frequency/month	-3.24***	-3.75**
	(1.11)	(1.50)
Waste bin evidence	5.95***	4.21**
	(1.41)	(1.90)
HWRC open/week	1.22*	1.89**
	(0.64)	(0.86)
Availability of free of charge HWRC	-0.67	-0.81
	(1.51)	(2.04)
Amount of separation drop-off sites	0.30***	0.30***
	(0.07)	(0.10)
Population/Separation drop-off sites	0.03***	0.01***
	(0.00)	(0.00)
Kerbside collection of recyclables	3.84**	6.20***
	(1.70)	(2.29)
Separation incentive program	5.32	10.17*
	(4.02)	(5.42)
Green waste collection	-0.02	-0.73
	(1.55)	(2.09)
Share of condominium dwellings	6.62	2.22
	(6.71)	(9.04)
Share of recreational dwellings	-9.64**	-10.20*
	(4.16)	(5.61)
Population/hectare of built-up area	0.15***	0.13**
	(0.04)	(0.05)
Constant	46.44***	52.02***
	(3.29)	(4.44)
No. of observations	463	463
Adj. R^2	0.38	0.21

*, **, *** stand for 10%, 5%, 1% statistical significance; standard errors in parentheses
Source: own calculations

3.3.1 Identified factors of efficiency

Conducted DEA showed several statistically significant municipal characteristics with respect to the WM management in the analyzed sample of municipalities. From my perspective they can be divided into several categories based on their nature:

1) Convenience factors: drop-off sites density and amount, kerbside collection
2) Incentive factors: incentive presence, waste bin evidence
3) Direct costs affecting factors: collection frequency
4) Indirect factors: recreational dwellings share, population density, HWRC opening hours

From the perspective of this thesis I find the most interesting first two categories, as in my opinion they offer the largest potential for further analysis and also can be directly influenced by the municipality. The direct influence can be also seen in case of collection frequency in the third category, but this relation is in my opinion quite straightforward (higher collection frequency translates into higher costs), and thus does not require further studying. Fourth category then contains factor that cannot be easily influenced by municipality and/or are related also to some other factors. HWRC opening hours for instance tend to correlate with the size of the municipality – larger one has more frequent opening hours, plus the overall separation options in a larger municipality a greater, thus the actual identification of relation between efficiency and HWRC opening hours might be a bit tricky. Moreover in this case we are dealing with a large heterogeneity in the data, as some HWRC are opened once per month while other every day, not speaking about the other issues like what actually municipalities consider as an HWRC. Final two characteristics, share of recreational dwellings and population density are indirect factors that are typically set and municipality has little measures how to practically influence them, but they could provide and explanation of certain relationships and municipality can adjust its WM accordingly.

3.4 Discussion of the findings and limitations

In both models MSW collection frequency per month has negative effect on the efficiency. Most of the municipalities in our sample have a biweekly collection of MSW, but with higher share of multifamily dwellings (typically areas with apartment buildings in the larger

municipalities), the trend leans toward weekly collection, which decreases MSWM efficiency. On the other hand, some municipalities have only monthly collection, and in several cases even less frequent collection periods (typically if a municipality has large central containers instead of smaller bins for each family house), which also increases their MSWM efficiency. Positive effect on efficiency with lower frequency makes sense, as less frequent collection directly transfers into lower MSWE, although the effect, as observed in per capita MSWE of municipalities with different frequency, is far from linear. Contrary to our results, De Jaeger et al. (2011) did not find any significant effect of different collection frequency on MSWM efficiency, although this might be caused by the differences among the sociodemographic characteristics of Flemish and Czech municipalities (triple the population density, much flatter terrain, average municipality more than tenfold larger, etc.).

Evidence of the amount of waste bins used in the municipality increases the observed efficiency of municipalities. The most common form of bin evidence is issuing yearly stamps or stickers that are physically attached to the bin, and declaring that the corresponding dwelling had paid its yearly MSW collection fees. An alternative to the stamps is for instance a sticker with a barcode, or in some very small municipalities the sole visual evidence by the municipal representative. Despite issuing stamps, in majority of municipalities there is no limit on the amount of bins, as long as the fees have been paid, so having an evidence system should not directly lead to the increased efficiency, even though the results suggest that with any kind of bin evidence present in the municipality. The reason behind this, as suggested by some municipal representatives, might be the observations that with evidence system people in the municipality voluntarily start to act more economically and often use rather one fully stuffed bin instead of two or three partially filled. Additionally, with bin evidence the municipality is able to control the amount of costs billed by the collection company much better – some municipalities reported a sudden drop in the amount of billable bins after the introduction of bin evidence, even if there was no visual difference in the amount of bins after the introduction of the bin evidence system.

More frequent HWRC opening days have positive effect on the efficiency. This is caused by the better availability of waste separation options for the people, who are therefore more likely to separate. If available, HWRCs in municipalities are on average open twice per week, with opening frequencies spanning between once a month up to six times per week.

Availability of a HWRC, which is typically free of charge to the people with permanent stay in that municipality (with occasional visits from other people being often tolerated), usually results in both less generated MSW together with higher ratio of separated waste to total generated municipal waste. Additionally I have examined the effect of the sole availability of a free of charge HWRC to the municipal population, whether directly in the municipality, or in some neighbor municipality as a result of intermunicipal cooperation. According to Bel and Mur (2009), Bel et al. (2014) or Põldnurk (2015), intermunicipal cooperation leads to the reduction in overall MSWE in municipalities with smaller population. In this case I was looking only at the availability of an HWRC. According to the results, there were no significant observed effects on the efficiency, suggesting that the availability of a free of charge HWRC outside of a municipality does not seem to matter that much – people likely do not consider this as an option, as it includes travelling to the other municipality.

The most common way of waste separation in the examined sample is separation through drop-off sites within the municipality, usually called separation "*nests*". These sites are used primarily for separation of paper, plastics and glass and, except very few, all municipalities in our sample have at least one such site. Therefore I do not examine whether the simple presence has some effect on the efficiency. With increasing average amount of people served by one drop-off site the efficiency slightly increases, meaning that municipalities with less frequent drop-off sites are more efficient, what might seem a bit counter-intuitive. Higher drop-off sites frequency means that they are closer to the people and the proximity, as concluded by González-Torre and Adenso-Diaz (2005) and others, acts as one of the important determinants in peoples' decision whether to separate their waste or not. The explanation behind this might be that municipalities from my experience often report expenditures related to the collection of separated waste from drop-off sites together with MSWE, and therefore with more drop-off sites the total amount of MSWE increases. Other explanation might be that in rural and less populated areas (which applies to many municipalities in our sample) people tend to separate less, as was observed by Põldnurk (2015). I have also examined the effect of increased density of drop-off sites with respect to the built-up area, but the results were not significant.

Some municipalities have adopted a kerbside collection of recyclables, mostly paper and plastics, occasionally also beverage containers. Such collection system of recyclables represents a very convenient way of waste separation for the people, as they can separate practically right at their household. Then, during scheduled dates, they simply leave the separated waste in front of their property. The most common type of kerbside collection in the Czech Republic is through plastic sacks; alternatively some municipalities have plastic containers. Containers are on one hand more durable, but on the other hand have significantly higher initial purchasing costs, are less flexible and the manipulation requires more effort – it has to be emptied right on the street and then taken back to the house, compared to throwing plastic sack into the truck without requiring any further attention from the people at the household. Presence of a kerbside collection system increases the efficiency quite notably, especially considering efficiency model 2, which includes the level of waste separation as one of the outputs. Such results are consistent with observations of Dahlén and Lagerkvist (2010), who concluded that municipalities with property-close collection of recyclables (in our case kerbside collection using plastics sacks) show twice as high separation rates. Folz (1991) came to the basically same conclusion that compared to drop-off sites, kerbside collection results in almost twice as high participation of the public in recycling. Kerbside collection represents a very convenient type of waste separation system for the people, and in several studies has been identified as the most important determinant of peoples' decision whether to separate their waste or not, what subsequently affects the overall MSWM efficiency.

In addition to the kerbside collection, some municipalities have adopted an incentive program for the waste separation, which allow people to get discounts from the waste collection fee based on the amount of waste they separate or some other benefits. This usually works with providing a unique identifier to each dwelling as a part of the kerbside collection and then by weighting the amount of separated waste from this dwelling. With such program adopted, people should be motivated to separate more, thus reducing the amount of total MSW, and resulting in the increased MSWM efficiency. However, I observed statistically significant positive effects of motivation system only in the case of efficiency model taking into account the waste separation levels, although in this case the effect was quite strong. Significance of such incentive program is supported by Hornik et al. (1995), who conclude that monetary

incentives work well in encouraging waste separation behavior. Additionally, Schultz et al. (1995) observed that using a lottery instead of fixed discounts results in even more separation.

Separate collection of biologically degradable waste should naturally decrease the amount of MSW and increase efficiency in the first model. Additionally, presence of such separation system should have even higher effect in the efficiency model 2, where the amount of separated waste is also considered. However, in the regression analysis this assumption proved insignificant. The reason behind this, suggested by several municipal representatives, is that majority of the municipalities in our sample consist primarily of single family houses where people are historically used to utilize their own green waste, resulting in the underuse of available options for green waste separation. On the other hand, other municipal representatives reported that, after some time, people often get accustomed to the new possibility of green waste separation, and previously underused capacities suddenly cannot keep up with the increasing volume of the green waste. With respect to that, if I take into account that in 2012 (the year from which I have collected the data for this analysis) the separation of green waste was something rather new for the majority of the municipalities (if they have adopted something like that at all), we might simply face the fact that it was too early to examine the effect of such factor on the MSWM efficiency.

According to the municipal representatives, MSWM in areas where majority of dwellings are in multifamily apartment buildings is usually considered as more problematic. People in such areas are more anonymous, usually share one large waste bin for multiple dwellings, and generally are less motivated to care about their waste-related behavior. Lebersorger and Beigl (2011) have observed such negative effect of increased percentage of condominium-type of dwellings on MSW generation, supporting the suggestions of the municipal representatives. Negative effect of a higher share of apartment buildings applies to the observed lower rates of waste separation as well. Ando and Gosselin (2005) confirmed this in a survey, according to which people living in condominiums reported lower waste separation rates than people living in single family houses. In contrast to the suggestion of municipal representatives, the main reason identified behind this behavior was not that people from condominiums have less of a sense of owning their waste stream, and thus caring less about their waste-related behavior,

but rather less convenience for such people with respect to the waste separation. Nevertheless, in our analysis this effect has not been confirmed, and results were insignificant.

The amount of dwellings used for recreation has an effect on MSWM efficiency as well. In municipalities with large recreational areas municipal representatives often said that such areas are problematic due to the seasonality in their waste generation (people use such dwelling mainly during summer and during the weekends), and that again such people care rather little about the state of their surroundings, if they visit these places only occasionally. Our results show that higher share of recreational dwellings in the municipality has a negative effect on MSWM efficiency. Observed effect may seem marginal, but in case of several municipalities with more recreational than regular dwellings this can have a relatively large impact on the overall efficiency. Increasing effect of higher share of recreational dwellings (called sometimes secondary residences) on MSW generation, leading subsequently to the decreased efficiency, has been also observed by Lebersorger and Beigl (2011).

The last factor that was examined is the density of population with respect to the built-up area of the municipality (the area where houses and related infrastructure are built, excluding lakes, fields, forests, etc. that are included in the total municipal area). Here I have observed positive effect of increased density on the efficiency. Although the results may again appear small and marginal, we need to consider that the population density is usually in the range of several hundred people per hectare, resulting in relatively strong overall effect. Positive effect of increasing density has been also observed by Benito-López et al. (2011) or Dubin and Navarro (1998), but only in municipalities with population under 20,000. In this sample there are only few municipalities larger than that, what might also contribute to the significance of the density factor. Such results therefore suggest presence of some economies of scale in more densely populated municipalities, but as was mentioned, this might hold true only until certain size of the population. To support that, Worthington and Dollery (2001) conclude that the efficiency of MSWM provision notably decreases with density, which confirms previous results, as in their case they were examining MSWM of rather large metropolitan areas.

In this chapter I had explored the potential factors influencing MSWM efficiency. As an appropriate and common method for efficiency evaluation I used two-stage DEA. In the first stage I have calculated the efficiency in models using MSWE as the input, while using the municipal population, built-up area and the amount of dwellings as the outputs, resp. adding the amount of separated waste and the ratio of separated waste to total municipal waste in the second efficiency model, further stressing the environmental aspect of analyzed efficiency. The sample used in the research consists of 463 municipalities in the South Moravia Region in the Czech Republic and the data were collected with respect to year 2012.

After calculating the MSWM efficiency scores I have subsequently applied OLS regression analysis using various MSWM characteristics collected from the interviews with municipal representatives. I have identified positive effects on the efficiency in case of lower MSW collection frequency, presence of waste bin evidence system, more frequent opening days of an HWRC, availability of a kerbside collection of separated waste, an incentive program for the waste separation, and higher population density. On the other hand I have identified a negative effect of increased density of drop-off sites, increased share of apartment-type dwellings on total dwellings, and increased ratio of recreational dwellings to regular dwellings. All of these observations, except negative effect of drop-off site density, are consistent with previous researches in this area. Contrary to the assumption, the availability of green waste separation did not prove to have a significant effect on MSWM efficiency, which might be caused by it simply being a relatively new separation option to the majority of municipalities at the time of the data collection. Compared to the previous researches in this area, I have focused on a broader range of factors usually connected with MSWM efficiency and provided results regarding their effects on MSWM efficiency.

The contribution of the conducted analysis is two-fold. First, by using proposed two-stage DEA one is able to identify efficient units in the first stage. Subsequently, in the second stage of analysis one can identify which specific factors related to MSWM have a statistically significant contribution to the efficiency and whether this contribution is positive or negative. In case of factors that can be influenced or adopted by the municipalities, such knowledge can be utilized by less efficient municipalities for improving their efficiency in this area.

Conducted analysis has some drawbacks too. Data from multiple years could provide a better understanding of the issue, but some of them simply are not available. Central institutions that collect them do not have an obligation or the will to share them, what limits further analysis of newer data. Collecting data directly from the municipalities can be demanding as well. Increased range of the municipal characteristics could have been used in the analysis, but this is again related to the availability of the data and substantial time requirements in order to get them. In some cases the data might be incorrect as well, whether due to the mistake while reporting them by the municipal representatives or while processed at the centralized database. In such cases municipality might become a peer even if the reality is different and subsequently influence efficiency scores of other DMUs in the sample.

Used efficiency evaluation method – DEA, has its limitations. First of all, it unsurprisingly takes into account only municipalities included in the sample. Therefore the results cannot be simply generalized and are valid only for the municipalities included in the analysis, as there is always a possibility that there is also some other municipality with some other mix of characteristics that, if included in the analysis, would become a peer and thus would affect the results. But with sufficient sample that covers majority of the municipalities in the examined area, the likelihood of existence of additional municipalities that could notably change the calculated results becomes slim.

Inclusion of qualitative findings might add further explanation to the factors influencing efficiency of MSWM. But such large variability of these factors among the examined sample of municipalities makes it difficult to incorporate them directly into the analysis. Nevertheless, I at least included these qualitative findings in the previous chapter.

4 EFFICIENCY FACTORS IN THE SOUTH MORAVIAN MUNICIPAL SOLID WASTE MANAGEMENT

The following chapter examines in more detail selected factors of efficiency identified either in the relevant literature or during the quantitative analysis of the collected data. Based on the conducted DEA evaluation I chose to examine in more detail factors related to the convenience in WM, specifically presence of kerbside collection and the density of drop-off sites, and the presence on an incentive program related to municipal waste separation. Based on the literature review I have chosen to examine more in detail age structure of the municipality, presence of the competition and the ownership nature of the WM company. I have selected these factors primarily due to the research potential they, in my opinion offer, and also due to the availability of data, which is a necessary condition for any further analysis.

Besides results of the analyses themselves (including the specification of the used datasets and methods), in each following subchapter I include a brief overview of the literature relevant to the examined issue.

4.1 Incentives, distance and kerbside collection[13]

In this subchapter I consider a better solution for MSWM to be the one that increases waste separation. In the previous chapter I explained that higher waste separation has usually direct impact on the lower mixed residual waste generation. Municipality then does not have to pay costly mixed waste treatment and instead pays much less for separated waste or even profits from selling such waste. This clarification is necessary in order to avoid using simple input/output measure like costs per ton of waste, where better solution would be both one with lower costs or alternatively one with higher waste generation, which is not something desired. On the other hand, higher waste separation rate represents a desired output – logically, if all waste is separated, there is no mixed residual waste, which I perceive as the desired state.

When considering waste separation, Folz (1999) stresses the availability of infrastructure plays a key role in the peoples' willingness to separate. But the sole availability of facilities is

[13] This subchapter is a shorter version of Struk (2017a).

not enough, and Williams and Taylor (2004) note that the public needs to be educated in order to think of waste as a resource rather than as materials that just need to be thrown away. Further important factors relevant for waste separation, namely the convenience of the overall process, are provided in Kirakozian (2015), Derksen and Gartrell (1993), Chen and Tung (2010), Oskamp et al. (1991), and McCarty and Shrum (1994). Importance of the convenience is further stressed by Williams and Taylor (2004), González-Torre and Adenso-Díaz (2005), Domina and Koch (2002), Perrin and Barton (2001), Hage et al. (2009), and Ando and Gosselin (2005). Instead of convenience, multiple studies, such as González-Torre and Adenso-Díaz (2005), Hage et al. (2009), or Belton et al. (1994) mention distance (proximity) to the waste separation facility, what can be also interpreted as the level of convenience or the effort required. Ayalon et al. (2013) suggests also the importance of proper targeting of the waste policies to the specific household groups.

The available waste separation infrastructure can be divided into groups based on the level of separation convenience they provide. González-Torre and Adenso-Díaz (2005) have categorized these from to the least convenient, HWRC (according to Schultz et al. (1995) most comprehensive but also most expensive) to the most convenient in the form of a kerbside collection p people separate their waste correctly. In the middle stands a drop-off – cheaper than HWRC, but less convenient than kerbside collection (for further insight on practical applications of kerbside collection throughout the world reader is referred to Gillespie and Bennett (2011), Derksen and Gartrell (1993), Zheng et al. (2017), Wilson and Williams (2007), or Saphores and Nixon (2014).

In case of the Czech Republic, kerbside collection is mostly realized in the form of a "*sack collection*". Compared to the kerbside collection using bins, plastic sacks are for one-time use only, do not require as high initial investment, and can be easily manipulated with. On the other hand, given the nature of the sack, limited types of recyclables can be collected with this method, with paper (including cardboard) and plastics being the most common. Such system is then easily connected with rewards, forming effectively and waste related incentive program. Strong effects of introducing practically any kind of rewards is mentioned by Schultz et al. (1995) or Williams and Taylor (2004). More on the issue of incentives related to kerbside collection in the Czech Republic is available in Struk (2017a), where the most

common form of a "*reversed*" PAYT (a system where people get discounts from usual waste fee based on how much waste they separate contrary to traditional Pay-As-You-Throw, where people pay for each additional waste they generate. For a further discussion of the various aspects of incentive programs in WM is the reader referred to Šauer et al. (2008), Slavík and Pavel (2013), Bilitewski (2008), Dijkgraaf and Gradus (2004), Fullerton and Kinnaman (1996), Bucciol et al. (2015), or Shaw and Maynard (2008).

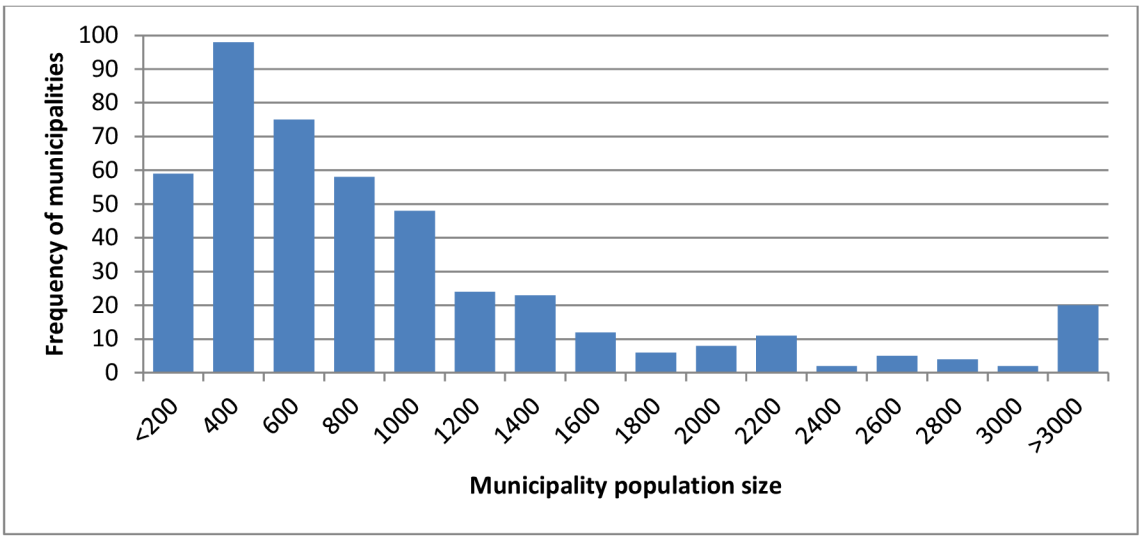
The research goal of this subchapter is to evaluate whether kerbside collection, higher density of drop-off sites and having an incentive program result in higher separation rates for paper and plastics in a sample of municipalities from the South Moravian Region in the Czech Republic.

Material and Methods

Municipal solid waste management 2012 data of 455 municipalities in the South Moravian Region in the Czech Republic were used in this study. The municipalities were selected based on the data that were accessible via email survey or phone call. Sizes of the municipalities ranged from population of less than 200 to over 3000. Figure 12 shows frequency distribution of these municipalities based on their population size. Compared to the whole Czech Republic, municipalities sampled in this study are a bit larger, but otherwise follow the same distribution. Few municipalities with significantly larger populations were not included in this study, as they usually have much more complex MSWM practices, and cannot be easily compared with small municipalities.

Waste quantity data were acquired from ISOH (Waste Management Information System), a Czech reporting system for waste producers administered by CENIA. Further quantitative and qualitative data, like amount of drop-off sites in the municipality, presence of kerbside collection, or usage of an incentive program were collected directly from the municipalities. The qualitative data were transformed into the dummy variables that were used in the subsequent analysis.

Figure 12: Frequency distribution of municipality population size of the sample, 2012 state



Source: CZSO

Qualitative data were collected during 2014 via telephone calls directly to the people responsible for solid waste management in the municipalities. The query consisted of a standard set of questions about MSWM, including questions regarding the presence of an HWRC, drop-off sites (sites count and collected waste fractions), availability of kerbside collection (including pickup frequency and collected waste fractions), provision of any incentives related to the separated waste collection and details on how incentives are applied.

Incentive programs in the sample took mostly form of mentioned "*reversed*" PAYT. Other minor incentive programs included a standard PAYT or a waste fee differentiation depending on the chosen waste collection frequency (practically realized, for instance, by different color of the sticker on the waste bin, so the waste collector can clearly identify the bins to collect).

As shown in Table 9, data were collected from 455 municipalities (673 total in the region), with average population of 923 (median 580) and built-up area of 0.158 km^2 (16 hectares). Data on built-up area were used instead of the total area (9.50 km^2 on average per municipality) as it represents the actual area where people live and generate waste, excluding the forests, lakes, meadows, etc. Each municipality includes on average 319 dwellings and 4.12 drop-off sites. This equates to 4.47 sites per 1000 population, 12.94 sites per 1000 dwellings, or 0.29 sites per hectare.

Table 9: Descriptive statistics of the municipalities in the sample

455 municipalities (2012 values)	Bottom value	1st quartile	Median	3rd quartile	Top value	Average
Population[1]	37	301	580	1027	21681	923
Dwellings[1]	14	107	196	340	8456	319
Area (ha)[1]	42	503	783	1215	5484	950
Built-up area (ha)[1]	1.5	7.2	11.7	18.2	212.3	15.8
Drop-off sites[3]	0	2	3	5	113	4.1
Drop-off sites per built-up ha[1,3]	0	0.17	0.26	0.37	1.74	0.29
Residual MSW (t)[2]	9	59	117	223	4123	196
Residual MSW per capita (kg)[1,2]	64	170	208	242	1505	219
Paper and plastics (t)[2]	0	4	9	21	642	20
Paper and plastics per capita (kg)[1,2]	0	11	16	23	84	18

Source: [1]CZSO, [2]ISOH and [3]own data

From the Table 9 I point out the top residual MSW per capita value of 1505 kg, which is very high compared to the rest of the municipalities in the sample. The reason behind it is that the given municipality has permanent population of approximately 50, but also additional more than 200 recreational dwellings within the cadaster. Therefore the actual amount of people generating waste is much higher than the official count, leading logically to the very high per capita values (using the permanent population count). The second highest value, around 1000 kg per capita, was reported in the municipality with landfill within its cadaster, and the WM company in exchange does not require any payments for MSWM in this municipality. As a result, people there generate as much waste as they like, because they are not charged for it in any way, and even people from other municipalities bring in their waste, avoiding charges in their municipality. Besides these two, the highest per capita values were up to 700 kg.

To reach stated research goal of this subchapter, I used simple statistical methods for the comparison of municipalities' performance, and then answered the following three questions:

1) whether the presence of a kerbside collection system has a positive impact on the separation rate;
2) whether the presence of an incentive program has a positive impact on the separation rate, and
3) whether a higher density of drop-off sites has a positive impact on the separation.

For testing the hypotheses I used OLS (ordinary least squares) regression technique, which estimates the coefficients of selected variables in a specified linear function with the goal of minimizing the sum of the squares of the differences between observed data points and points predicted by the specified function. As a dependent variable I used the separated waste rate, representing the percentage of separated waste (in this case paper and plastics) from the total sum of separated plus residual waste, like in for example Bucciol et al. (2015).

After the necessary transformation of the qualitative data into dummy variables, I used the following variables in the regression analysis:

- Separation rate (dependent variable) – the percentage of separately collected paper and plastics waste fractions in the municipality from the total generated municipal solid waste (including residual waste, recyclables waste fractions, etc.)
- Kerbside collection (independent variable) – a dummy variable, 1 if municipality was using kerbside collection for the separate collection of paper and plastics waste fractions, 0 if not
- Incentive program (independent variable) – a dummy variable, 1 if municipality was using some kind of incentive program in order to increase the separate collection of recyclable waste fractions, 0 if not
- Drop-off site density (independent variable) – the amount of drop-off sites in the municipality per hectare of built-up area, amount of drop-off sites based on the information provided by the municipal representatives

I continued with the regression analysis and tested the three hypotheses:

- Municipalities with kerbside collection system have higher separation rate (H_1)
- Municipalities with incentive program have higher separation rate (H_2)
- Municipalities with higher density of drop-off sites have higher separation rate (H_3)

I tested each hypothesis separately and then tested the joint hypothesis that can be formally written as

$$separation\ rate = \beta_0 + \beta_1 kerbside + \beta_2 incentive + \beta_3 drop\text{-}off\ density + \varepsilon$$

where β_0 stands for constant,

β_n stands for coefficient of independent variable, and

ε stands for random error component

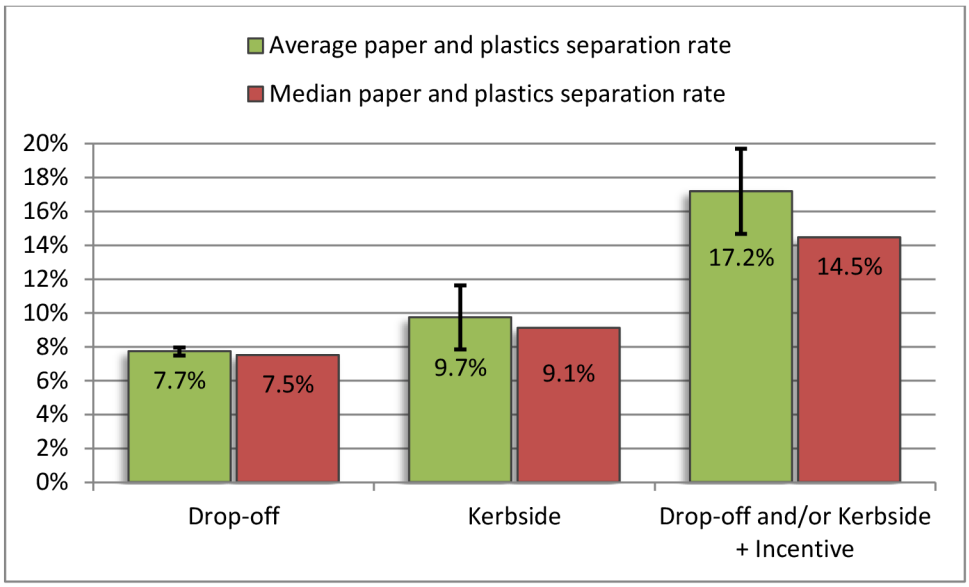
Results

First I show the results of a statistical analysis of the sample of municipalities divided into the three categories based on their recyclables collection system (Figure 13). The first category contains municipalities that use only drop-off sites and no kerbside collection or incentive program. A total of 379 municipalities fall under this category, with average paper and plastics separation rate of 7.7% (median 7.5%).

The second category contains municipalities that use only kerbside collection system for paper and plastics but no incentive program or drop-off sites. There were 7 municipalities in this category, with an average paper and plastics separation rate of 9.7% (median 9.1%).

The third category contains municipalities that implemented some kind of incentive program with either drop-off sites or kerbside collection, or both. There were 10 municipalities in this category, with an average separated paper and plastics rate of 17.2% (median 14.5%). If we consider subgroup of municipalities with incentive program and both drop-off sites and kerbside collection (6 units), their average paper and plastics separation rate is 21.0%.

Figure 13: Average and median paper and plastics separation rates



*standard errors are 0.2% for drop-off, 1.9% for kerbside, and 2.5% for drop-off/kerbside with incentive
Source: own construction

In addition, 55 municipalities form the sample used some combination of kerbside collection and drop-off sites (usually at some remote part of the municipality) without any incentives with average separated paper and plastics rate of 9.6% (median 9.0%) and 4 municipalities that used only occasional mobile collection of recyclables with average separated paper and plastics rate of 4.4% (median 3.1%).

Table 10 contains results of the OLS regressions. The first model tests H_1. Results indicate that kerbside collection increases separation rate by 2.9%. Considering the base level of separation represented by the constant (7.7%), this means that a kerbside collection system increases the paper and plastics separation rate by almost 40%. Acquired result that this factor can increase municipal separation level is statistically significant, thereby confirming H_1.

The second model tests H_2. Results indicate that incentive program increases separation rate by 9.3%, which more than doubles the total separation rate compared to the base level represented by the constant (7.9%). Acquired result that this factor can increase separation level is statistically significant and thus confirms H_2.

Table 10: Estimated effects of collection systems and incentives on separation rates (in %)

	H_1 Kerbside collect. model	H_2 Incentive program model	H_3 Drop-off sites density model	Joint model
Kerbside collection	2.89*** (0.65)			2.63*** (0.65)
Incentive program		9.26*** (1.56)		8.04*** (1.55)
Drop-off sites density (per hectare)			3.21*** (1.16)	3.95*** (1.12)
Constant	7.70*** (0.25)	7.93*** (0.23)	7.20*** (0.41)	6.41*** (0.42)
No. of observations	455	455	455	455
Adj. R^2	0.039	0.070	0.014	0.115
P-value (F)	<0.001	<0.001	0.006	<0.001

*, **, *** statistical significance of the coefficient at 10%, 5%, 1%; standard errors in parentheses
Source: own calculations

The third model tests H_3. Results indicate that additional drop-off site per built-up hectare of municipal area increases separation rate by 3.2%. A density of one drop-off site per built-up hectare is in practice quite high. In our sample, the average density of 0.29 sites per hectare of built-up area corresponds to one drop-off site per area of a circle with 105 m radius. Again, acquired result that higher density of drop-off sites can increase separation level is statistically significant and proves our assumption in H_3.

The final joint model includes all three examined factors together. It shows again that all of the individually examined factors are statistically significant. Based on this model it is possible to estimate the impacts of individual examined factors on paper and plastics separation rates for a municipality with information about the presence of the factors.

Here I note that in the sample only 11 out of 455 municipalities did not have drop-off sites – therefore the constant in the regression model can be used as a proxy for the municipality with only drop-off sites for waste separation plus eventually some other factors not captured in the data (the constant in the joint model excluding these 11 municipalities was 6.42, which is practically identical to the joint model of the full sample). None of these 11 municipalities have an incentive program, but 7 have kerbside collection. Average separation rate of this subgroup was 7.8%, which is comparable with municipalities with only drop-off sites (Figure

13). Remaining 4 municipalities that do not have drop-off sites or kerbside collection have average separation rate of 4.4%. Their waste separation is conducted through occasional mobile collection of recyclables with possible use of some municipal property as a temporary storage facility. Nevertheless, this subgroup of municipalities is very marginal and represents less than 1% of the sample population and thus has practically no impact on the results.

Table 11 shows differences in average total MSW generation and amount of separated paper and plastics between municipalities without incentive program (455 municipalities) and those with some kind of incentives (10 municipalities). With incentive program present is the amount of MSW 20% lower (28% lower for just residual waste), while the amount of separated paper and plastics is 71% higher (regression model suggests even higher increase).

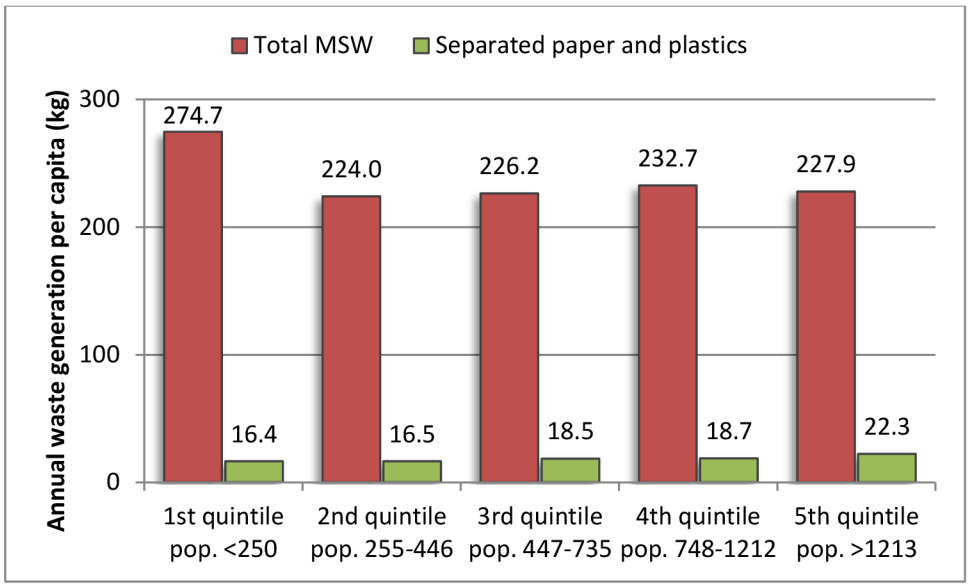
Table 11: Average amount of generated waste per capita with and without incentive program

Municipal average value	Total MSW per capita (kg)	Residual waste per capita (kg)	Paper and plastics per capita (kg)
No incentive program (445 municipalities)	238	220	18
Some incentive program (10 municipalities)	190	158	31
Change if incentive program is present	-20%	-28%	+71%

Source: own calculations

Finally, I have examined whether the amounts of generated MSW and collected recyclables change with the size of the municipalities. Municipalities were sorted according to their size and equally divided into five groups (quintiles) from the smallest to the largest (Figure 14, values represent averages from individual municipal values, information about sizes of municipalities are under quintiles). In case of the total considered generated MSW (in our case the sum of residual MSW, paper and plastics) we observe a slightly higher (20%) generated amount among the smallest municipalities. In the rest of the sample average values are stable and vary only by few per cent. In case of separated paper and plastics per capita we can see an increasing trend with the municipality size, with the increase between the first and the fifth quintile being approximately 36% on average.

Figure 14: Average amount of generated waste per capita according to the municipality size



Source: own construction

Discussion of the results

In this study I did consider only MSW (waste produced by households in the municipalities) that represented 17% of the total waste generation in the Czech Republic in 2012. I did not consider industrial and commercial waste, which in many developed countries accounts for majority of the total generated waste. Compared to MSW, industrial and commercial waste streams seem to be notably better developed in the Czech Republic, as the utilization of these wastes was in recent years close to 80%, compared to less than 50% of MSW. Also the landfilling rate of industrial and commercial waste was slightly over 10%, compared to more roughly 50% in case of MSW (MŽP, 2017b). The reasons are both in more stringent industrial and commercial waste legislation, and that it is much easier to clearly identify the producer of this waste, unlike with the municipalities, where the producers are the households. Also in case of industrial and commercial waste the payments for waste treatment are notably higher, creating much stronger incentives for the companies to take better care of their waste.

I also did not cover other important types of recyclables, such as glass and green waste, as these types of waste were not typically collected through kerbside collection in 2012. If I included them, the total separation rates would be significantly higher, as glass and green

waste are much heavier types of waste compared to considered plastics or paper. According to MŽP (2017b), total MSW separation rate in the Czech Republic is over 30% in the recent years, compared to 10% if considering just paper and plastics examined in this study.

As was mentioned, convenience of waste separation, usually interpreted as the perceived availability of waste separation sites (Derksen and Gartrell, 1993; Chen and Tung, 2010), or alternatively the distance to the nearest waste separation site (González-Torre and Adenso-Díaz, 2005), is a key factor of participation in separation. The willingness of people to separate can thus be defined as a function of the perceived availability/distance to the nearest separation site (in our case represented by variables of kerbside collection and drop-off sites density). Much empirical research was conducted on this issue with the only difference between the results in the actual magnitude of the effect of distance, as it is affected by many variables that might be related to the specific place where the research took place. These include, for instance, the usual habits of the households, housing structure, type of waste collection systems, education of the people, or how well the people are informed about the available waste separation options and benefits of it (Martin et al., 2006).

I did not examine whether individuals decide to separate waste, like Knussen et al. (2004), Knussen and Yule (2008), or Miliute-Plepiene et al. (2016), but how much they separate. However, the psychology behind this is basically the same. With less effort needed/more convenient separation system/less distance to the nearest separation site (Perrin and Barton, 2001) and, eventually, a proper incentive, people will participate in separation more often, resulting in a higher recyclables separation rate. Results showed highly significant effects in waste separation under these different scenarios.

Also, since it is common to have both an HWRC and a drop-off site right next to each other, practically forming just one waste collection facility, I did not test the presence of an HWRC as a factor affecting paper and plastics separation rate.

Concerning the quality of the collected recyclables, it is ensured by the collecting company that checks it on every pick-up, whether it is the drop-off site or kerbside collection. If the recyclables are contaminated by other inappropriate waste fractions, it is further considered as regular residual mixed residual waste and charged accordingly. Based on my experience, this happens very rarely, and municipalities are very active in explaining this to the people, who in the end bear the additional costs. Very little contamination of recyclables in case of kerbside collection was observed also by Wilson and Williams (2007).

Results from Figure 13 show the potential of implementing incentive program to the municipal waste separation. While the difference between the pure drop-off sites collection and pure kerbside collection is more than a quarter in favor of kerbside collection, combination of these two systems did not show any notable difference compared to the pure kerbside collection, both in terms of average separation rates or statistical significance of their interaction, unlike in Sidique et al. (2010). Implementing incentive program, however, doubled the separation rates, and this strong impact was verified also in the regression model.

While both groups of municipalities (kerbside collection without incentives; any incentives implemented) are relatively small, standard errors of averages show that achieved values are statistically significant, suggesting that the impact is consistent. However, one drawback with this collection system is that the kerbside was generally reported by municipal representatives as more expensive than drop-off sites, had municipality previously used them and therefore could compare. Thus, it is in the end more of a political decision whether municipality is willing to accept higher costs for higher separation rates and convenience. This issue becomes even more important in case of implementing incentives. If not properly planned, increased separation rates might be outweighed by the additional costs. Moreover, as Thøgersen (2003) or Halvorsen (2012) note, shifting an intrinsic motive to separate waste based on one's belief to purely economically motivated behavior could become an issue, once the incentives are no longer perceived as paying off.

Positive impact of kerbside collection on waste separation levels (tested in H_1) was confirmed. Multiple studies, for instance Ashenmiller (2011), Dahlén et al. (2007), Wilson

and Williams (2007), or Dahlén and Lagerkvist (2010), confirm significant impact of door-to-door separation systems on waste separation and estimate the increase in separation rates up to 100% (in our case 40% increase). Our relatively lower results might be caused by, for instance, already high separation rate without kerbside collection. Also, in some municipalities the kerbside collection was implemented only recently, and it might take some time until the households understand and adjust to this collection system, as appropriate communication strategy of the municipality plays a crucial role (Mee et al. 2004).

The generally most convenient separation system, kerbside collection, showed the highest paper and plastics separation rates in our sample. Such results confirm previous studies. For instance, Barr et al. (2003) concluded that access to the kerbside waste separation (in our case in the form of the sack collection) greatly enhances waste separation behavior, Folz (1991) concluded that the participation of public in the waste separation is almost twice as high with kerbside separation system compared to the drop-off sites system, or Abbott et al. (2011) identified expansion of a kerbside waste separation as a key factor in UK's improved recycling performance.

An interesting related observation reported by the local representatives is that the sole visibility of the kerbside waste separation (in our case, a sack filled with recyclables at the edge of the property) may motivate others (i.e. neighbors) to take part in the waste separation process. The "*created*" social pressure on the non-participants can be perceived as another benefit of the kerbside separation system that tends to work in smaller municipalities with limited anonymity of the people. Positive effects of such social interactions between neighbors on recycling behavior have been examined in more detail by Shaw (2008).

Positive impact of incentives on waste separation levels (tested in H_2) was confirmed. Similar results were acquired by, for instance, Allers and Hoeben (2010) or Bucciol et al. (2015). Incentive programs are generally accompanied by a kerbside collection system, or some other system that allows matching of the waste producer with the acquired reward. Bucciol et al. (2015) calculated combined effect of kerbside collection and incentive on the waste separation rate of municipalities from selected Italian district to be almost 17%, while in our

case it was almost 11%. However, mentioned study considered also additional recyclables, therefore the results for paper and plastics could be in fact similar to ours. When considering evidence from using standard PAYT, Sidique et al. (2010) estimated that incentives in the form of variable pricing could increase the rate of recycling by up to one third, and were the most important factor in the total separation rate. These results suggest that if an incentive program for waste separation is present in the municipality, the willingness of the people to separate waste tends to increase dramatically. But unlike in the case of standard PAYT, "*reversed*" PAYT used in the Czech municipalities motivates municipalities only to increase waste separation, and not to dispose of the waste in questionable ways.

Finally, testing H_3 confirmed positive impact of higher drop-off site density on waste separation. However, the real impact should not be overestimated. Average density in our sample is 0.29 sites per hectare of built-up area. According to the joint model, to match the impact of a kerbside collection system it would require increasing the density from 0.29 to 0.96, which means more than tripling the amount of drop-off sites. Especially in larger municipalities with many drop-off sites this is unlikely to be economical. NIMBYism (Not In My Back Yard) might become an insuperable issue here as well (Byrne and O'Regan, 2014). And at last, our model assumes constant returns to scale of additional drop-off sites, while municipal representatives mention rather decreasing returns to scale, thus further worsening the potential of this measure.

The calculated adjusted R^2 values in estimated models were relatively low, but the statistical significance of the examined factors was very strong in all cases. Inclusion of control variables such as municipality size produced slightly higher adjusted R^2 values, but the coefficients of examined independent variables remained practically similar, thus I do not report these models. Low R^2 indicates weak ability of the model to predict the values of dependent variable, suggesting that additional variables should be used to explain more of the variance. However, in our case the goal is not to predict the separation rates, but to estimate the impacts of selected independent variables. In cases like this we are therefore interested primarily in statistical significance of the coefficients of independent variables rather than R^2 values of the models. Low R^2 values are reported also in comparable models from other studies, for instance Ashenmiller (2011) reports pseudo R^2 of 0.125, or Sidique et al. (2010)

report pseudo R^2 of 0.08, and 0.11 when using log of separation rate as a dependent variable. In other studies, like Dahlén et al. (2007), R^2 values are not reported at all, as the focus is on the coefficients of independent variables. I have also found evidence of models with R^2 higher than 0.6 in Bucciol et al. (2015), but in this case panel data from 10 year period were used in models with 15-20 independent variables, unlike in our case. Our examined variables thus might not be the major contributors to the separation rate in individual municipalities, but they consistently explain certain trend, which is the focus of the study.

Results in Table 10 stress the environmental benefits of an incentive program. Even though there are only 10 municipalities with incentives, the decrease in residual waste and increase in separated waste is notable. Linderhof et al. (2001) and Dijkgraaf and Gradus (2004) analyzed waste generation of municipalities for several years after implementing incentive program and report even larger decrease in the residual mixed waste in general, although recyclables did not increase as much as in our case. But this might be caused simply by higher initial level of the waste separation in their samples. While some could argue that the decrease in residual mixed waste generation is a result of, for instance, illegal dumping, with the employed "*reversed*" PAYT system I do not consider this to be likely cause.

Size of the municipality (Figure 14) could have some impact on the amount of generated and separated waste. Higher average values of generated waste per capita in the smallest municipalities in our sample are, in my opinion, caused partially by the fact that these smallest municipalities are primarily located in the countryside and often include second homes or cottages, where people generate waste, but are transient residents, thus not influencing amount of permanent population.

On the other hand, higher amount of collected recyclables per capita in the largest municipalities in our sample is most likely caused by generally better separation options in larger municipalities with more drop-off sites, and at least one HWRC. Also, due to the higher population density, distances to the closest separation options are shorter, which equals to the higher convenience, thus making people more likely to separate.

This research could be further expanded by examining impacts of analyzed factors on other types of recyclables, although not many of them are consistently collected using drop-off sites or kerbside collection. Adding multiple years could also provide additional information on waste generation and separation change throughout time. Using more variables, for instance socioeconomic characteristics of municipalities, or MSWM related characteristics like waste collection frequency, could also shed some more light on the issue, but such data are often not centrally available, making it difficult to create an appropriate dataset for the analysis.

Finally, in this study I have not examined the added benefits of examined measures in economic terms. Increased convenience of the kerbside collection and higher amount of separated waste could be possibly evaluated by cost-benefit analysis, or appropriate non-market valuation method. Performing a cost-benefit analysis by the interested municipality with its own data and taking into account its unique characteristics is generally recommended before considering adoption of any of the examined measures. Especially appropriate valuation of social impacts in the economic part of the cost-benefit analysis can prove to be difficult, while possibly having the crucial impact on the analysis outcome.

Partial conclusions

I examined the waste separation systems of drop-off sites, kerbside collection and the impact of incentives on waste paper and plastics separation rates. My findings confirmed that the less effort needed for waste separation, and the lesser distance to the nearest waste separation site, the more waste people separate. The presence of drop-off sites and kerbside collection system resulted in approximately 7.7% and 9.7% paper and plastics separation rates. However, incentivizing the local population can increase separation rates significantly to 17.2%. Impacts of analyzed factors on the waste separation rates were examined also in the regression analysis, and were found to be statistically significant. Compared to the most common collection through the drop-off sites, kerbside collection increases separation rates by 2.6%, incentive program by 8.0% and 1 additional drop-off site per hectare (sample average is 0.29 per hectare) by 3.9%. Adding an incentive program can thus more than double the usual separation rates.

Results from this research can be utilized by municipalities planning to significantly improve their waste separation rates. Introducing an incentive program can have a great potential to increase the waste separation, without necessarily high investments from the municipality, if appropriately designed. However, it is recommended that a cost-benefit analysis is to be done before adopting any of the analyzed measures.

The limitation of these results are in the fact the examined efficiency factors were identified in the DEA models using sample of municipalities only from South Moravian Region in the Czech Republic. Therefore the validity for the rest of the Czech Republic might be questioned. In my opinion limited initial sample does not present that much of a problem. The reasons for that is the fact that the Czech Republic is not that large country and the differences between individual regions are not that large. If excluding Prague (which is practically one large city, and in such MSWM tend to work differently than in an average municipality), average monthly wage in individual Czech regions was in 2012 between 760 EUR and 875 EUR (based on data from CZSO), which translates to 15% difference. Furthermore, used dataset includes more than 500 municipalities, therefore any outlier should have only marginal effect on the final results, if they are present. Additional remarks could be towards the prevailing lifestyle of the people in various parts of the country, but South Moravian Region includes both larger and smaller municipalities, municipalities in dominantly agricultural areas as well as in more remote woods and in general should not be significantly different from common municipalities in other regions of the Czech Republic.

4.2 Age structure[14]

In this subchapter I focus on identification whether age structure of the municipality has some effect on it WM, and if what is this effect for various age cohorts. Previous initial studies of this issue in the Czech Republic were made by Soukopová et al. (2013), Soukopová and Kalina (2012), or Hřebíček et al. (2013). Foreign studies of the effects of sociodemographic factor include, for instance, Hockett et al. (1995), Daskalopoulos et al. (1998), Dennison et al. (1996), Sterner and Bartelings (1999), Dyson and Chang (2005), Martin et al., (2006),

[14] This subchapter is a shorter version of Soukopová, Struk and Hřebíček (2017), to which MS contributed significantly with the parts dealing with methods, material, discussion and conclusions; and Struk and Soukopová (2016), to which MS contributed significantly with all the parts.

Bandara et al. (2007), Beigl et al. (2004, 2008), Hage and Söderholm (2008), Johnstone and Labonne (2004), Martin et al. (2006), Sterner and Bartelings (1999), Mazzanti and Zoboli (2008), Benítez et al. (2008), Pickering and Shaw (2015), Gellynck et al. (2011), Lebersorger and Beigl (2011), Brown (2015), or Talalaj and Walery (2015). However, none of these studies includes a more detailed analysis of the age structure that simply dividing the population to those roughly under 14, those between 15-64, and those over 65, what is our opinion greatly insufficient, and a more detailed analysis of this issue seems appropriate.

The main aim of this subchapter is then to examine how the age structure influences municipal waste generation, waste separation and related waste expenditure using statistical and econometric analysis. We have used available data regarding age structure, municipal waste generation and waste expenditure from more than 5000 Czech municipalities. The results show notable differences between people of various age, and how the average waste generation of people changes throughout their life. Our findings could help municipalities to better focus their measures on specific age groups in order to achieve better MSWM results.

The area of study in both cases of waste generation and waste expenditure comprises the whole Czech Republic. The Czech Republic has one of the lowest levels of MSW generation in the EU, with slightly over 300 kg/year/capita (Eurostat, 2015). The reasons for lower MSW generation are closely related to the population's purchasing power, consumer behavior and the frequency with which consumer goods are replaced, which is lower in Central and Eastern European countries than in the countries of Western Europe. A door-to-door collection system of MSW, that has been dominantly used in the Czech municipalities since 1990s contributes to this low generation of MSW as well.

Waste expenditure models method and material

We previously analyzed the cost of MSW with respect to the multiple socio-demographic parameters available in data obtained from municipalities during the national census that took place in 2011 (Struk, 2015b). Several models from this study produced statistically significant effects of parameters such as age and housing structure, and the amounts of people that are

economically active, unemployed or retired on final MSWM expenditure levels. In this part of the study we focus on the effects of various age categories on MSWM expenditure levels.

The analysis, which involved both explorative data analysis and multiple regression analysis, was conducted at the municipality level and used data from the years 2011 and 2014 due to its availability and quality. The program packages Microsoft Excel 2011 and gretl (version 2015d) were used for the analyses.

The initial sample consisted of all Czech municipalities (6,251 in 2011 and 6,253 in 2014), but this was reduced to approximately 6,150 municipalities. First, the sample was reduced by removing all municipalities reporting the absence (or a zero value) of MSW expenditure (resulting in new totals of 6,212 in 2011 and 6,222 in 2014). The sample was then sorted based on the MSWE per capita level, and the extreme values were removed from the top and bottom of the list (trimming the top and bottom 0.5% (31+31) municipalities from the list), resulting in a sample of 6,150 municipalities. Besides these changes, no other adjustments to the sample were made.

One thing to note here is that these data are based on expenditure reported by the municipalities themselves. It is therefore possible that some municipalities have reported incorrect data, but it is practically impossible to double-check this for all 6,000+ municipalities which provided the data. Still, we only expect such misreporting to happen in case of very few and rather small municipalities that often lack qualified personnel, or due to individual mistakes. The overall distortion in the results due to this should be therefore practically marginal, if any.

In our MSWE models, the basic cost function for MSWE takes the following form:

$$MSWE = f(Pop)$$

MSWE represents the total expenditure of municipalities in the Czech Republic on the management of municipal solid (residual) household waste and is explained as a function of

population. MSWE includes the collection, transportation, and disposal of MSW (such services typically take the form of regular collection/pick-up, transportation to a waste treatment facility and the MSW treatment itself). It does not include expenditure on recycling or irregular capital/investment expenditure such as the purchase of new collection vehicles, new treatment plants, etc. We used the population of the municipality as the independent variable as it is available practically instantly from the statistical office and in general are unlikely to contain incorrect entries. Moreover, in several calculations population variable showed very high correlation with MSW generation, therefore it can be seen also as a certain proxy for waste generation – more on this later in the subchapter.

In order to develop the models we have used the standard ordinary least squares regression (OLS) method and have calculated multilinear regression from the available data, as some other authors (Hockett et al., 1995; Lebersorger and Beigl, 2011). We have transformed the values obtained for absolute expenditure and population into relative values (expenditure per capita; the proportion of the population found in each age category) and therefore have not incurred the problem of heteroskedasticity that would otherwise usually occur with such data (i.e. when estimating a model with some municipalities that are far larger than the others). The normality of the distribution of the residuals has also been confirmed. Because of this, the use of OLS is justified in our case. Due to the significance of the acquired results it was not necessary to apply more advanced econometric models.

Our dependent variable in the expenditure models is then MSWE per capita (*MSWMEpc*), while the independent variables Age_{i-j} are the proportions of people living in a municipality in certain age categories from year i to year j ($i < j$ are integers) with regard to the total amount of people living (with permanent residency) in that municipality. The age categories are 0-14; 15-19; 20-29; 30-39; 40-49; 50-59; 60-64; 65-69; 70-79; and over 80[15].

[15] The categories 0-14; 15-19; 60-64 and 65-69 exist due to the need to ensure compatibility with CZSO methods – In the past, CZSO used to divide the population into only three age categories: 0-14; 15-64 and 65+.

A formal description of Model 1, based on the cost function (above), is then:

$$MSWMEpc = \beta_0 + \beta_1 Age_{0-14} + \beta_2 Age_{15-19} + \beta_3 Age_{20-29} + \beta_4 Age_{30-39} + \beta_5 Age_{40-49} + \beta_6 Age_{50-59} + \beta_7 Age_{60-64} + \beta_8 Age_{65-69} + \beta_9 Age_{70-79} + \beta_{10} Age_{80+} + \varepsilon$$

In Model 2 we used only the independent variables $Age_{20\text{-}29}$, $Age_{30\text{-}39}$, $Age_{40\text{-}49}$, $Age_{50\text{-}59}$, $Age_{60\text{-}64}$, $Age_{65\text{-}69}$, $Age_{70\text{-}79}$ and Age_{80+} because we focused only on variables which we expected to have a greater impact on the independent variable. In Model 3 we then simply tested just economically active inhabitants, using the variables $Age_{30\text{-}39}$, $Age_{40\text{-}49}$, $Age_{50\text{-}59}$, $Age_{60\text{-}64}$ and $Age_{65\text{-}69}$. In this last model we did not include $Age_{20\text{-}29}$ variable as, especially in last years, people often tend to study until their late twenties and delay moving out from their parents.

The population of the Czech Republic at the end of 2014 was 10,538,275. In terms of population density, the Czech Republic is above the European average, with 131 inhabitants per km^2. Its age structure shows a clear increase in the over 65+ age category, which refers to retired people by default (amount of people retiring in recent years is strongly affected by people born after World War II, who began retiring after 2010). Overall, the average age increased in 2011-2014 from 41.1 to 41.7 years (CZSO, 2018). When looking at the basic categories used to describe the age structure in the Czech Republic (the three main categories 0-14; 15-64; and 65+) in Table 12, we can see a 2% increase in the amount of people in the oldest age category, while the proportion of the people in the "*productive*" age category decreased by almost 3%. The proportion of the population in the oldest age category is most likely to keep on increasing thanks to the improvements being made to healthcare provision, which are causing people to live longer overall.

Table 12: People in the main age categories in the Czech Republic, 2011 and 2014

Age	Amount of people in 2011	Share of total (%)	Amount of people in 2014	Share of total (%)	Change in share (%)
0-14	1,488,928	14.32	1,601,045	15.19	0.88
15-64	7,267,169	69.87	7,056,824	66.96	-2.91
65+	1,644,836	15.81	1,880,406	17.84	2.03

Source: The authors, based on data from CZSO

Age category data were acquired from the CZSO[16]. For 2011 we used data from the national census, while for 2014 we used statistical data from that year. We have chosen 2014 because the CZSO publishes more detailed data about age categories in municipalities only since 2014. The normality for the share of each age category in the total municipal population of each of the municipalities from the sample has been visually checked via a frequency histogram, not showing any notable deviations from the normal distribution. MSWE data were acquired from the MONITOR web portal run by the MF ČR. It provides complete linked open data concerning revenue and expenditure for every Czech municipality in the given years. We have focused specifically on the category of current municipal expenditure related to MSW collection, transportation and subsequent treatment.

Waste generation models method and material

Data on waste quantity were acquired from CENIA. At the time of our research, the most recent data were provided for 2013. These data contain amounts of annual production of generated waste fraction for the Czech municipalities. Although it is natural that every single municipality produces at least some waste, these data are not available for all municipalities. This might be caused either by some technical errors, or simply because responsible municipal representative did not provide the data. Especially in case of very small municipalities with no professional staff the municipal representative might simply prefer to do more important things than reporting such data.

For clarification we note that as MSW we consider mixed residual waste – unsorted waste that ends up in a landfill or in an incinerator, without any further utilization. As separated waste we consider a sum of any municipal waste that is separated and then somehow utilized – it consists mostly of separated paper, plastics, glass, biodegradable municipal waste, metal, or other relevant waste fractions (more details on the issue of municipal waste content are in

[16] Municipal socio-demographic data are published by CZSO as linked open data. They are publicly downloadable, along with a detailed description of the method by which they are collected and what these data actually represent. We have used data from this source regarding municipal age structure, such as the amount of people in various age categories in each Czech municipality. To be more specific, the CZSO has published data for each 5-year age cohort since 2014. However, the data from 2011 is taken from the national census, in which data for each 10-year age cohort were collected. After merging these two sources, we were able to acquire comparable data regarding age structure for 10-year age cohorts for both 2011 and 2014. By doing this we got 10 age groups that we use in the analysis, compared to only 3 age groups available in the previous years and in many foreign studies.

Chapter 1). Depending on the available separation options in individual municipalities, some of these fractions might not be separately collected, and therefore ended up as mixed residual waste in examined years – but we did not examine this in more detail in this study.

Age structure data for individual municipalities in 2011 and 2014 were acquired from CZSO, as was described in the previous section. As the most recent waste data were available for 2013, we decided to use the age structure data from 2014 together with the waste generation data from 2013. We assume that the changes in the age structure between the two consecutive years are marginal, and therefore would not create any significant distortion in the results.

OLS method was again used for the analysis. As we have two sets of cross-sectional data that are not from consecutive years, we have analyzed both datasets separately. Problem of heteroscedasticity was avoided again by using per capita values for waste generation and percentage of people in the individual age groups on total municipal population. Considering the normality of the data distribution, in case of the age groups we did not observe any notable irregularities. In case of waste generation per capita, the distribution was a bit between normal and a Poisson distribution, with slightly longer tail towards higher per capita values and slightly higher concentration of data points at the lowest per capita values. The longer right-tail is simply explained by the fact that the data are naturally limited on the left side by the zero value, but are not limited in their maximum value – in this kind of left-bounded data this is normal. Higher concentration of the very low values is caused by the fact that many municipalities reported very low amount of total generated waste, which we assume was not always correct, but we do not have any measures how to safely identify municipalities with certainly incorrect data. In order to eliminate at least the extreme outliers, we have trimmed our sample at several levels, and provide the models for each of these trimmed subsamples in order to check, whether the calculated results are consistent.

Considering the sample, there was 6251 total municipalities in the Czech Republic in 2011 and 6253 in 2013. In the analysis we left out municipalities that did not report any values for generated MSW or separated waste – both cases are most likely due to some errors, as providing MSWM is compulsory for the Czech municipalities according to the law, together with providing at least some basic options for waste separation. We used several subsamples

for the subsequent regression analysis, varying in the trim level from the full sample. Description of these subsamples is provided in the Table 13, together with the mean and median values per capita for both years and for MSW and separated waste.

From the data description we can see that MSW generation in the Czech Republic is approximately 300 kg of total municipal waste per capita per year (residual plus separated waste fractions). Compared to the EU-27 average of 500 kg per capita per year, this is a notably lower value. According to Závodská et al. (2014), the reasons for that are partly historical with the traditional thriftiness and lower standard of living in the Czech Republic compared to the western countries, both leading to a lower wastage rate, and partly due to the observed fact that in case of the Czech municipalities, reported data cover only waste produced by the households, while in the case of some other countries these data cover also waste from municipal sweepings and public parks. This is a result of slightly different definitions of municipal waste and its fractions in various countries, as stressed in Hřebíček and Soukopová (2017). Therefore the actual difference in MSW per capita generation in the Czech Republic is not that much lower compared to other EU countries, as it might seem from the data. In our case this methodological issue does not matter much, as we are dealing with the data only from the Czech Republic, which are therefore consistent.

Table 13: Reduction of the amount of municipalities in the subsamples

		2011		2013	
	Trim level (bottom+top)	Reduced municipalities	Final amount in the subsample	Reduced municipalities	Final amount in the subsample
Residual municipal solid waste	0.33%	17+17	5082	18+18	5268
	0.50%	26+26	5064	27+27	5250
	1.00%	51+51	5014	53+53	5198
	<20% & >500%	255+6	4855	170+6	5128
Separated solid waste	0.33%	19+19	5752	20+20	5990
	0.50%	29+29	5732	30+30	5970
	1.00%	58+58	5674	60+60	5910
	<20% & >500%	592+66	5132	488+42	5500

Source: own calculations

Results and Discussion – Municipal solid waste expenditures

The results of OLS estimates of *MSWEpc* based on data concerning the age structure in municipalities from 2011 and 2014 are presented in Table 14.

Table 14: OLS estimation, Czech municipalities, 0.5% trimmed sample

Dependent variable: MSWE per capita (CZK/year)

	Model 1		Model 2		Model 3	
	(2011)	(2014)	(2011)	(2014)	(2011)	(2014)
const	-221.1	-820.9**	-16.12	94.62	-47.03	-68.88
	(191.6)	(373.9)	(98.85)	(197.5)	(60.42)	(117.3)
Age_{0-14}	404.5*	1270***				
	(229.0)	(431.1)				
Age_{15-19}	-411.5	-313.8				
	(283.4)	(594.4)				
Age_{20-29}	-285.3	189.0	-494.4***	-741.9**		
	(234.3)	(454.2)	(170.3)	(339.3)		
Age_{30-39}	593.3***	859.2*	477.9**	166.7	444.6***	393
	(226.8)	(455.4)	(197.4)	(400.4)	(138.2)	(276.1)
Age_{40-49}	1609***	2494***	1268***	1400***	1210***	1566***
	(230.8)	(435.5)	(193.7)	(381.8)	(169.8)	(318.3)
Age_{50-59}	1955***	3026***	1757***	2074***	1716***	2022***
	(237.1)	(486.1)	(152.5)	(306.7)	(144)	(296.2)
Age_{60-64}	2643***	3030***	2430***	2107***	2523***	2294***
	(261.6)	(515.5)	(187.6)	(370.4)	(173.3)	(344.8)
Age_{65-69}	1207***	3085***	1028***	2114***	1316***	2490***
	(286.4)	(524.7)	(221)	(379.9	(209)	(351.9)
Age_{70-79}	854.6***	1676***	666.5***	764.2**		
	(285.7)	(542.1)	(185.7)	(342.2)		
Age_{80+}			-370.1*	-962.0**		
			(217.8)	(419.1)		
n	6150	6160	6150	6160	6150	6160
Adj. R^2	0.0668	0.0244	0.0672	0.0232	0.0644	0.0211

Standard errors in parentheses

* statistically significant at 10%; ** statistically significant at 5%, *** statistically significant at 1%

Source: own calculations

Model 1 clearly shows the trend of gradually rising *MSWEpc* with increasing age up to the 60-64 age group, where *MSWEpc* reaches what is by far its maximum value. After that peak there is a sudden drop in *MSWEpc*, which continues further with increasing age. We found the very high *MSWEpc* peak for the 60-64 age category (compared to other age categories) very interesting. We have also estimated econometric models with absolute MSWE values and

absolute quantities of people in municipalities (although there are naturally problems with heteroskedasticity even if we use robust standard errors or heteroskedasticity-corrected models), but the results suggest the same trend with *MSWEpc* peak at the 60-64 age category. This result has very strong statistical significance (p-value<0.01) in basically every model we have estimated (see Struk, 2015b for additional models from 2011). This result is interesting because it does not correspond to the outcomes of studies from outside the Czech Republic (Sterner and Bartelings, 1999; Beigl et al. 2008).

The aspect of ageing was also examined in Sterner and Bartelings (1999) and Beigl et al. (2008), but no conclusions were reached regarding its importance, unlike the results shown above. In our opinion this might be caused by the insufficient definition of what constitutes the senior population in these studies.

As ageing is part of a natural and continuous process of change in individuals, it is important to clearly define the moment when middle-aged people become seniors. Multiple approaches and methods exist for defining seniority objectively (Stuart-Hamilton, 1999). Most commonly, the start of seniority is based on the chronological (calendar) age, but this measure itself does not provide any deeper information, as it is usually just an administratively set age. In modern western societies the beginning of seniority is usually considered to be the moment when people leave work in order to retire. This usually occurs around the age of 60-65. The majority of gerontologists agree with this age. Vohralíková and Rabušic (2004) note in this context that "*today it is the norm to work until the age of 60 or 65*", but do not provide any further explanation. In the Czech Republic the retirement age has increased in recent years due to the parametric adjustments occurring as part of social reforms (the calculated retirement age in 2011 was approximately 62 for males and 59 for females, while in 2014 it was already 63 and 60, respectively). However, based on the current formula for calculating the size of pensions, if a person is willing and health-wise fit enough to do so, it is beneficial for him or her to stay in work if such an option is available (and many people take this opportunity) in order to secure higher retirement compensation later. Additionally, many studies further stress the key impact of retirement on consumption behavior, which subsequently affects related waste generation.

Once we had obtained such a result, we began to think about what the reason might be for such a spike in *MSWEpc* in the 60-64 age category in 2011 and in the 65-69 age category in

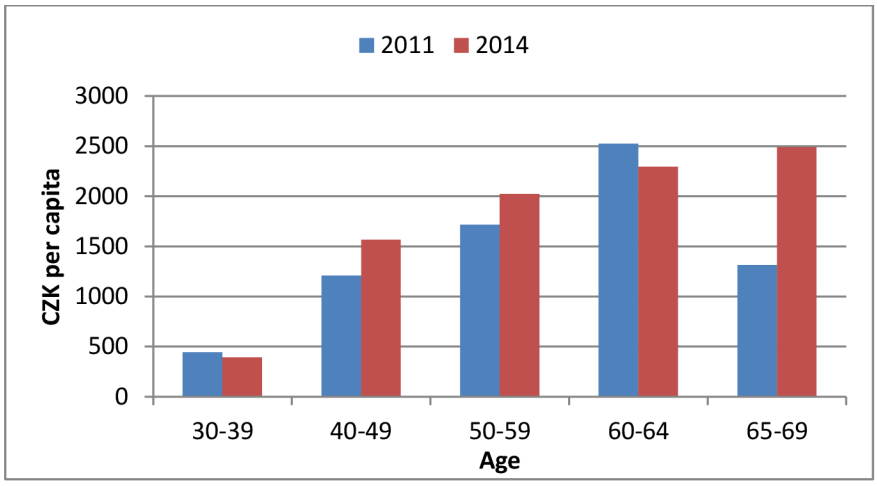
2014. The first idea was that people at such age are usually the most experienced individuals in the job market, and therefore should earn the most money and be able to consume the most goods, resulting in the highest amount of generated waste. Well, this is partially true – such people are on the one hand the most experienced, but on the other they also often have problems adjusting to new technologies and processes, they are starting to experience health problems and are generally starting to prefer having more leisure time instead of staying at work. It may therefore hold for some at this age that they are at the peak of their earning potential, but many others are long past that point. For this reason we discarded the income-consumption theory behind the *MSWEpc* peak. Then, instead of giving further considerations to what might have caused this spike, we simply asked the people around us who are in this age category about whether and how they have changed their waste-related behavior. One of the authors of this study is actually in this age group, and comments from his perspective regarding waste generation correspond to the statements made by other people of a similar age who were asked.

From the obtained answers we have deduced that once people reach 60 years of age, they begin to prepare themselves for their actual retirement, which in the Czech Republic usually occurs a few years after one reaches 60 (as we have mentioned earlier in the text). One important part of their preparation is often the physical adjustment of their household (or moving to a different place if the individual can afford it), consisting of (among other things) reconstruction work, the replacement of ageing household goods, and going through all the things one has accumulated during one's life, deciding what to keep and what to discard. This is all usually done with the goal of getting one's household into a state where it will require minimal further adjustments over what may possibly be the next few decades. What all these "*preparatory*" activities have in common is the generation of waste, and if one considers that this is a kind of "*once-in-a-lifetime general clean-up*" of things one has accumulated during the past forty years or so, there is very likely to be a lot of waste generated (at this point we would add that, unlike in for example the USA, in the Czech Republic it is rather uncommon to hold something like a yard sale of the old unnecessary things, resulting in probably much less waste generated during this period). This idea also supports the observation that despite the general decline in income that people experience after reaching their 60s (which means that they do likely consume less than before), they are still able to generate more waste by

discarding previously accumulated goods. Moreover, with the over 70 age category we have estimated a notable decrease in the coefficient's effect on their *MSWEpc*. This is in accordance with the observed behavior of elderly people, who tend to generate a rather low amount of waste, as noted by Pickerin and Shaw (2015). Based on all this we have come to the conclusion that this *MSWEpc* spike in the 60-64 age category is not actually caused by the age itself, but rather by the retirement process, which occurred around the age of 60-64.

With the continually increasing age at which people in the Czech Republic retire, it occurred to us to verify this conclusion by looking at data from later years. This became possible with the data from 2014, which cover the same variables as in 2011. We theorized that if the retirement age itself increased in combination with the tendency of many people to further extend their working career past their retirement age, there should be some kind of observable shift in the 60-64 *MSWMEpc* spike from 2011 to the next age category (65-69) in 2014. The model estimated from 2014 data did indeed show exactly this kind of shift. This is depicted in Figure 15, which displays the levels of estimated coefficients for the age categories obtained from Model 3 for 2011 and 2014.

Figure 15: Municipal solid waste expenditure per capita for 2011 and 2014



Source: own construction, based on data from MONITOR and CZSO

The 2011 spike for the 60-64 category is clearly visible, while in 2014 (apart from the overall higher *MSWEpc* levels) there is no longer a single spike for the 60-64 age category, but rather a shift in the high *MSWEpc* levels to the next 65-69 category. This observation further

supports our theory concerning the linkage between the retirement process and the high levels of *MSWEpc* at around the age when retirement occurs.

Another explanation may be the fact that the average age of retirement has been increasing over the given 3 years thanks to parametric retirement reform (the regular retirement age was 61 in 2011 and 64 in 2014). Moreover, the key moment from the perspective of consumption is the start of retirement, as emphasized in many studies.

In Model 2 we left out the 0-14 and 15-19 age groups. One reason for doing so is that keeping all age categories represented by their proportion of the total population would result in obvious collinearity. Another reason is that, unlike the rest of the age structure data provided by the CZSO which is divided into age decades, the 2011 data for children is divided into the 0-14 and 15-19 categories (instead of 0-9 and 10-19). Finally, children in the Czech Republic generally stay at home with their parents until their late teens, what affects their waste-related behavior to a large extent. However, from Model 1 it is clear that children tend to have rather low *MSWEpc*, and are thus comparable with people in the over 70 age category. In particular, children aged 15-19 tend to cause very little *MSWEpc*, while the *MSWEpc* level of the youngest children is affected by their diapering period in their first years. The results of Model 2 are similar to the results of Model 1, with the difference that the variable $Age_{20\text{-}29}$ became statistically significant. These results are very interesting because they show that young people tend to contribute notably less to the waste expenditures than people in other age groups.

In Model 3 we focused on variables which are related to economically active inhabitants (omitting 20-29 age group, as explained earlier). The results of Model 3 further confirm the results obtained in Models 1 and 2.

Results and Discussion – Municipal solid waste generation

Results for per capita generation of MSW are in Table 15, and per capita generation of separated waste in Table 16. Both tables include several models differing in the trim level of

the full sample resulting in slightly different subsamples, but otherwise contain same variables. In order to avoid collinearity, we had to leave out one of the age groups – in our case age group 0-14. This age group was left out specifically because it contains the largest age span, and the members of this group can have very different waste-generating behavior. For instance little infants can produce notably more residual waste per day than average people in the form of diapers, while teenagers are more likely to produce very little waste due to their budget constraints – they simply cannot generate that much waste if they do not consume that much. Such tendencies to behave very differently within one age group are much less likely to be present in other age categories.

Table 15: Residual MSW generation per capita for the individual age groups

	0.33% bottom+top trimmed sample		0.50% bottom+top trimmed sample		1.00% bottom+top trimmed sample		<20% & >500% mean trimmed sample	
	2011	2013	2011	2013	2011	2013	2011	2013
const	144.4**	106.5**	143.6**	85.34*	140.3***	91.24*	81.82	100.4*
	(57.92)	(51.26)	(56.42)	(50.10)	(53.67)	(47.91)	(58.18)	(52.20)
Age 15-19	-188.5	-13.52	-184.0	34.90	-162.3	-3.379	-203.6*	-175.2
	(117.5)	(115.6)	(114.4)	(112.8)	(109.1)	(108.0)	(116.1)	(117.7)
Age 20-29	-201.9**	-229.8***	-174.6**	-208.5***	-133.3*	-165.2**	-184.5**	-239.4***
	(87.29)	(79.15)	(85.08)	(77.24)	(80.94)	(73.78)	(88.10)	(80.64)
Age 30-39	-13.69	37.20	-23.46	98.46	-9.791	109.3	123.3	45.39
	(106.8)	(100.1)	(104.1)	(97.86)	(99.02)	(93.72)	(107.9)	(102.1)
Age 40-49	80.07	169.1*	67.70	206.1**	75.67	205.4**	174.9*	189.5**
	(92.76)	(86.69)	(90.41)	(84.60)	(86.02)	(80.86)	(92.60)	(88.28)
Age 50-59	300.9***	296.4***	294.7***	293.3***	270.3***	248.8***	431.2***	359.1***
	(80.06)	(72.83)	(78.01)	(71.03)	(74.34)	(67.83)	(78.71)	(73.66)
Age 60-64	479.8***	309.1***	478.4***	313.2***	412.8***	324.1***	552.5***	314.3***
	(94.99)	(86.74)	(92.66)	(84.54)	(88.42)	(80.76)	(94.02)	(88.38)
Age 65-69	421.1***	469.3***	415.7***	446.8***	468.6***	399.8***	618.3***	567.0***
	(112.2)	(88.93)	(109.5)	(86.88)	(104.3)	(83.32)	(111.5)	(90.57)
Age 70-79	231.7**	266.9***	242.9***	301.0***	175.3**	243.5***	228.0**	297.9***
	(93.22)	(81.89)	(90.83)	(80.09)	(87.17)	(76.64)	(92.26)	(83.91)
Age 80+	-99.67	7.751	-87.97	7.837	-13.41	17.92	45.80	55.78
	(112.3)	(99.38)	(109.9)	(96.93)	(104.6)	(92.78)	(110.9)	(99.78)
# of obs.	5082	5268	5064	5250	5014	5198	4855	5128
Adj. r^2	0.0283	0.0232	0.0292	0.0218	0.0266	0.0183	0.0409	0.0326

*, **, *** stand for statistical significance at 10%, 5%, 1%, standard errors in parentheses
Source: own calculations

We also stress out that the provided values in the models should not be taken literally – for instance understanding the negative values as that the presence of people of this age group in the municipality actually decreases the generated MSW. Instead the calculated coefficients should be perceived more likely as the suggested trend. The correct interpretation is that the

age group with lowest (even negative) coefficient values tends to contribute the lowest to MSW generation, while the group with the largest coefficient values does the opposite.

Provided models show notable differences of the MSW generation per capita between age groups. Lowest values of coefficient were acquired by the youngest age groups 15-19 and 20-29, with values for the latter being consistently statistically significant regardless of year or the subsample. Such results suggest, that the people aged 20-29 contribute the lowest. From our perspective are these results in accordance with the fact that people in this age group are usually still students, or are at the beginning of their working careers, in both cases with limited budget, subsequently resulting in low consumption and low waste generation.

The following age group 30-39 does not have any statistically significant results, but from the values we can expect that their waste generation per capita is increasing, which would be in accordance with the common fact that these people are usually working, and thus able to consume more, resulting in more generated waste.

Age group 40-49 has significant results in year 2013, suggesting that their contribution to the MSW generation is becoming higher compared to the younger groups. In our opinion this is caused by their further extended budget due to their longer job experience.

Age groups spanning from 50 up to 79 have all high and significant coefficients regardless of year and subsample. Such results suggest that people in these age groups contribute the most to the overall MSW generation. The highest (peak) values can be observed among the 65-69 and in some cases also the 60-64 age groups. This suggests that throughout the lifetime, people are likely to generate the highest amount of MSW during this age period and after that, the amount decreases. Our interpretation of these observations, in our opinion, cannot rely solely on increasing consumption budget of these people, as people in the Czech Republic usually commence retirement at around the age 62 (plus minus few years, depending on the sex and both the availability and willingness to continue working), and also people at this age often prefer not to work that hard at their jobs as when they were younger. We have observed a similar thing when examining municipal expenditure related to waste management, and our idea here is again the same as with the MSWE model in previous section – that people at

around this age prepare their households for the retirement, what often includes some reconstruction, refitting the household with different equipment, replacing it, and getting rid of things that will likely not be used anymore.

Finally, the oldest age group 80+ does not produce any significant results, but from the values we can expect that these oldest people tend to produce very little amounts of waste. This is most likely the result of decreasing consumption budget, as they do not work anymore, and that they tend not to buy a lot of new things, as they likely already have what they needed.

If we look at the differences between the years 2011 and 2013, in general they are not that high (a constant has to be included into the consideration, as it is statistically significant in most cases). We can observe that in case of the age group 20-29 the effects on decreasing MSW generation are bit stronger, suggesting that people in this age group are continuing to generate less MSW per capita. Same positive trends can be seen in the age groups 50-69, where in all cases the contribution to MSW generation seems to be lower than in 2011. On the contrary, in case of the age group 40-49 the effects seem to be stronger, suggesting that per capita generation of MSW by this age group increases – but in this case only 2013 results are statistically significant (2011 coefficient is significant only in the last subsample). In case of eldest people in the age group 70-79, the effects are approximately the same in both years.

Based on the provided results for MSW per capita generation, we suggest further researches to focus more on the age groups 40-79, and specifically on the age group 60-69. Results suggest that these groups produce largest amounts of MSW per capita, therefore they presents the greatest possibilities for campaigns and measures oriented towards waste reduction, especially in case of people around the age when commencing retirement. On the other hand, it seems that the people in the age group 20-29 (and partially 15-19) seem to be doing already well in these aspects, without need to extend the activities focused on them much further.

In Table 16 we provide models with similar independent variables as previously, but this time the dependent variable is the amount of separated municipal waste per capita.

Table 16: Separated municipal waste generation per capita for the individual age groups

	0.33% bottom+top trimmed sample		0.50% bottom+top trimmed sample		1.00% bottom+top trimmed sample		<20% & >500% mean trimmed sample	
	2011	2013	2011	2013	2011	2013	2011	2013
const	45.72	8.935	51.62*	15.24	54.26**	23.06	43.02	23.69
	(29.79)	(23.63)	(27.95)	(22.50)	(25.28)	(20.79)	(26.56)	(22.78)
Age 15-19	75.24	170.1***	89.48	166.5***	84.30	145.7***	104.9*	112.8**
	(62.16)	(53.76)	(58.34)	(51.15)	(52.39)	(47.32)	(54.34)	(51.45)
Age 20-29	43.52	113.5***	52.64	100.5***	57.09	60.89*	85.33**	68.09*
	(45.54)	(36.69)	(42.72)	(34.92)	(38.63)	(32.28)	(40.60)	(35.03)
Age 30-39	-76.50	22.19	-83.16	15.14	-80.68*	7.200	-61.50	11.26
	(54.86)	(45.68)	(51.47)	(43.51)	(46.59)	(40.21)	(49.05)	(44.09)
Age 40-49	-3.570	-19.63	-29.84	-38.09	-13.26	-28.83	3.284	-29.71
	(47.83)	(39.47)	(44.93)	(37.58)	(40.67)	(34.70)	(42.67)	(38.26)
Age 50-59	31.29	69.75**	16.04	81.50**	-4.874	88.39***	11.45	83.44***
	(40.88)	(33.54)	(38.38)	(31.90)	(34.71)	(29.49)	(36.12)	(32.28)
Age 60-64	141.2***	111.9***	133.1***	97.81***	86.84**	97.27***	93.51**	97.23**
	(47.84)	(39.79)	(44.92)	(37.86)	(40.69)	(34.90)	(42.51)	(38.21)
Age 65-69	-14.97	37.30	-59.11	22.07	-59.58	0.3651	-60.11	18.81
	(57.13)	(40.85)	(53.62)	(38.98)	(48.25)	(36.00)	(49.97)	(39.48)
Age 70-79	19.03	99.76***	29.83	88.65**	33.41	79.36**	53.10	89.34**
	(47.88)	(37.46)	(44.93)	(35.65)	(40.34)	(32.94)	(41.70)	(36.04)
Age 80+	99.90*	109.9**	106.7**	108.8***	81.67*	60.23	143.3***	147.1***
	(56.09)	(44.20)	(52.63)	(42.04)	(47.34)	(38.97)	(50.11)	(43.15)
# of obs.	5752	5990	5732	5970	5674	5910	5132	5500
Adj. r^2	0.0050	0.0070	0.0064	0.0083	0.0055	0.0068	0.0080	0.0097

*, **, *** stand for statistical significance at 10%, 5%, 1%, standard errors in parentheses
Source: own calculations

Compared to the results of the MSW per capita generation models, we get less statistically significant results. Interesting observation is that in case of the youngest age group the values are among the highest (however, statistically significant mostly only in 2013). This suggests that the youngest people seem to separate the most, while also generating the least MSW. In our opinion this is consistent with previous note that these young people have already been affected by the waste-related campaigns at schools, and they try to behave pro-environmentally. If they have been raised with relevant information for which they, as students, had enough time to absorb, it often might seem natural to them to behave in this way. When we were contacting municipal representatives for gathering data about MSWM, many of them said that the school in their municipality plays an important role in the waste management in the way of educating young people and creating pro-environmental habits through various related activities. Once teenagers at schools were properly explained how to separate waste and what are the benefits of this activity, they often became actively leading the rest of the family towards higher separation (or to the waste separation at all). Therefore it

seems logical that in municipalities with higher percentage of people in this age group the separation amounts of waste would be higher. Some of this effects can be probably observable also among the next age group, 20-29, but this probably requires more time, as the people in this age group might not have been exposed to such campaigns towards waste separation and recycling when they have been teenagers.

The next two age groups, 30-49, seem to be separating waste the least, but the results are not statistically significant. Based on what the values suggest, it might be that part of these people tries so separate, while the other part does not, and therefore the results are inconsistent. It might also be that part of these people is keeping the habits of waste separation, while for the other part it might be less convenient to do so, for example due to less available time for it.

Age groups 50-64 seems to be contributing to the higher separation rates, and compared to the previous age group we perceive it as a positive shift. On the other hand, these positive effect might be simply a side product of the fact that these people tend to produce the highest amounts of MSW, and therefore if separating even just part of it, it will positively influence the total separation levels.

In case of the age group 65-69 are the effects on waste separation inconsistent, with the coefficients very close to zero. The interpretation might be the same as in case of the age groups 30-49, that part of the people in this age group is actively separating, while the other is not. If we accept the idea of people refitting their households at around this age (due to commencing retirement), another explanation might be that people are simply getting rid of all kinds of things that do not fit into any available separated waste fractions, and thus contributing mostly to MSW generation.

Finally, in case of the eldest people, we observe positive and mostly statistically significant results, suggesting that eldest people contribute to the higher separation. Especially in case of the age group 80+ the coefficients are among the highest, which is an interesting observation when considering, that this age group produces usually the lowest amounts of waste. In our opinion this might be caused simply by the fact that these people have usually enough time for waste separation and while doing it, they relate themselves with this pro-environmental

behavior, share their experience with other peers and generally perceive waste separation as something worth devoting their time to.

As we do not have that many statistically significant results in case of models of per capita separation levels, we do not draw any conclusions regarding the shift of the values between years 2011 and 2013 like in case of MSW generation models.

Partial conclusions

In this subchapter we analyzed how age structure can influenced MSWE and MSW generation, including waste separation. The added value of our study lies in the novel and innovative approach, giving consideration to new factors affecting MSWM. Society is affected by demographic change and as a result, demographic characteristics represent significant determinants that can influence MSWM. Understanding the interdependencies between age variables and the decisions made by householders regarding the production and management of waste can help municipal representatives to affect and manage MSWM and influence certain groups of people regarding their waste generation and waste separation.

We have estimated several models for both MSWE and MSW generation per capita using age structure data with people divided into 10 age groups. More than 6 000 municipalities in the Czech Republic have been used as a sample in our estimations using data from 2011 and 2013/2014. During our estimations we made an interesting discovery that the highest levels of MSWE per capita occur for the 60-64 age category. We have come to the conclusion that this MSWE per capita spike is not actually caused by the age itself, but instead by people coincidentally retiring at around that age. Based on our observation of the behavior of people around the time of their retirement, we have identified that this process is connected with many activities generating rather large amounts of waste (reconstruction of the home, the replacement of household goods, sorting and discarding one's belongings accumulated during previous decades, etc.). In our opinion it is therefore the actual process of retirement occurring around this age that causes such a spike in MSWE per capita. We also estimated the same models for 2014, where, based on the fact that the retirement age in the Czech Republic is slowly increasing and at the same time more and more people are staying in their jobs past

their retirement age, we expected a shift in the high MSWE per capita levels to the next 65-69 age category. This expectation proved correct in 2014 model, further supporting our theory of the connection between high MSWE per capita and the start of the retirement period.

The results of our research show that senior citizens of a certain age (after the start of retirement) have a surprisingly important influence on the generation of MSW and on expenditure devoted to dealing with it. These conclusions drawn on the basis of our models can also be tested in other countries where comparable data is available.

In case of age structure and the MSW generation and separation, our models including Czech municipalities from years 2011 and 2013 suggest that waste-related behavior of the various age groups is notably different. We have identified that young people under 30 tend to produce lowest amounts of residual waste per capita, while also being the best in the waste separation. On the contrary, people of age 50-79 seem to be generating the most mixed residual waste, while not separating correspondingly that much. Interesting finding was also that the eldest people, while generally producing little waste overall, seem to be among the best at waste separation.

Such findings can be again beneficial for the municipality when planning to improve the results of its municipal WM and planning to target information campaigns to the specific age groups (suggested also by Ayalon et al., 2013), instead of treating everyone as the same. Results in Table 16 suggest that there is no need to focus more attention to the youngest and the oldest people, as their waste-related behavior seems to be already relatively good (low MSW generation and high waste separation), and the improvement would most likely be marginal. Instead of that, the municipalities should focus more on the middle age groups 30-49 and 65-69, possibly including also the age groups between them. People in these age groups seem to produce inconsistent results regarding their waste generation and waste separation level, thus representing the largest possibilities for improvement, both in the area of MSW generation and the separation levels, which subsequently affect also MSWE.

4.3 Competition and public vs. private nature of the waste management provider[17]

In this subchapter I focus on the differences in the WM company ownership with respect to the municipal expenditure together with the possible importance of the competition in the relevant WM providers market. This study builds upon the available body of literature (Domberger et al., 1986; Kinnaman and Fullerton, 1999; Reeves and Barrow, 2000; Dijkgraaf and Gradus, 2003; Ohlsson, 2003; Bel and Warner, 2008; Bel and Mur, 2009; Bae, 2010; Jacobsen et al., 2013; Bel et al., 2010; Simões et al., 2012; Szymanski, 1996; Gomez-Lobo and Szymanski, 2001). In the Czech Republic was this issue with respect to WM services also examined by Nemec et al. (2005), Ochrana et al. (2007), Nemec et al. (2007), Merickova et al. (2014), or Nemec et al. (2017).

The aim of this subchapter is therefore to examine how changing a MSWM provider affects MSWE in given municipality. Unlike in other studies, which usually compare the differences between public and private providers, I use the empirical evidence to examine the difference in costs once the change occurred. In addition to that I also look at the difference between changing from private to public company and vice versa as well.

Methods and Material

There are two primary sources of our data. Financial data were acquired from the web portal run by MF ČR, MONITOR. This portal allows anyone to freely download complete detailed data for individual fiscal years for all municipalities in the Czech Republic. I used the current expenditure of municipalities on MSWM in order to compare day-to-day expenditure of municipalities on provision of MSWM and did not use capital expenditures, as was explained in the chapter 1. Current expenditure calculated per capita (using municipality population data available by CZSO) generally provide a good basis for expenditure comparison among the municipalities, as MSWE covers approximately same things both in smaller and larger municipalities.

[17] This subchapter is a shorter version of Struk (2017b)

I have collected municipal financial data for several consecutive years, making it possible to see their development over the time and also allowing to check whether there are any issues with the data, suggested for instance by a very high difference between individual years. This is usually a result of municipality reporting their financial data incorrectly. A typical example is reporting both current and capital expenditures as current, or when municipality does not differentiate between expenditures from a certain subgroups and report only aggregated expenditure under the most common category from such group. Reasons behind such mistakes were already explained earlier, and again I add that in my experience they do not seem to occur very often, thus the acquired results should be biased only marginally, if at all.

The second source of the data used in this subchapter was interviews with the municipal representatives from the sample of municipalities that was described in detail in chapter 3. As I examined the change of the WM company, I focused only on those municipalities that made such change. Unlike in the case of financial data, there is no centralized source where municipalities report how they secure their WM. Out of 500+ contacted municipalities 70 experienced a change of WM provider in the last several years. However, due to the very large interannual differences caused by reporting expenditures related to building an HWRC site together with the current expenditure I have dropped 4 municipalities, resulting in a final sample of 66 municipalities used in this study.

When it comes to the actual WM provider in these municipalities, most of them use an external WM company, as having an own company would not make economic sense. Due to that they contract external private, public, or a mixed WM company. I now define each of these ownership types in a way they are used throughout this subchapter, except for private company, which is self-explanatory.

A municipal WM company is usually historically created by a larger municipality for which it provides MSWM, and sometimes in addition provides this service also for a few surrounding municipalities. According to the interviews, such company is usually less focused on profit and is often part of a larger municipal company generally dealing with various technical municipal services. Providing MSWM for additional municipalities then serves as a way to

better utilize available infrastructure with more focus on the profit (thus practically acting like a private WM company, but in some cases it can still offer very reasonable conditions).

A public WM company then stands for a company owned by an association of municipalities where individual municipalities act as the shareholders based on their size and respective financial investments into the WM company. Each municipality still keeps paying this company provision for the MSWM services, but it also participates on the profits of the company. However, during the interviews I have noted occasional disillusions from municipal representatives with being part of such company, as small municipalities seem to have very little vote in it compared to few largest municipalities that in practice make all the decisions.

A mixed WM company is usually a result of previous decision of a larger municipality to partially outsource WM provision but still have some participation in the decision making and profit, in exchange for having an economically strong partner from the private sector. In such cases the mixed company often takes form of a newly created company owned partially by an already established player in the WM market together with the municipality. If relevant, such company also provides MSWM for surrounding smaller municipalities, just as in case of the municipal WM company.

Based on the telephone interviews with the responsible municipal representatives, or alternatively with the municipal representatives with the sufficient knowledge of the topic, I matched each municipality with the WM company, time horizon when this company provided MSWM in the given municipality and the type of the WM company ownership.

After that I have created a dataset for several consecutive years with information about municipalities and their WM company, its ownership type, related municipal expenditures and any change in WM company, had it occurred during the examined time period.

Tables 17-19 include some basic characteristics of the sample used in this study.

Table 17: Description of the sample of municipalities (with respect to the year of the change)

66 municipalities	Bottom value	Median	Top value	Average
Population	76	930	9 555	1 391
MSWE per capita	291 CZK	518 CZK	926 CZK	539 CZK

Source: CZSO, MONITOR

Table 18: Year of the waste management company change, 66 municipalities

Year	2008	2009	2010	2011	2012	2013	2014
No. of changes	2	8	5	6	14	19	12
% of the sample	3%	12%	8%	9%	21%	29%	18%

Source: own data

Table 19: Waste management company ownership before/after the change, 66 municipalities

Ownership	Private	Public	Municipal	Mixed
Before the change	50	8	6	2
% of the sample	76%	12%	9%	3%
After the change	31	29	4	2
% of the sample	47%	44%	6%	3%

Source: own data

In order to be able to analyze the effect of company change I had to adjust the data, as these were collected for a broader time horizon and thus difficult to compare. I have adjusted the dataset in order to have data in the format of MSWE in the year before the change (year -1), in the year when the change of the WM company occurred (year 0), in the subsequent year (year +1), etc. After that I have aligned the individual municipal data in order to have matching periods. By doing this I did not need to consider in which absolute year the change occurred, and constructed the relative timeline, which is more important for our purpose. So instead of having 66 changes occurred in 7 years horizon I acquired dataset with company change occurring in the same relative period.

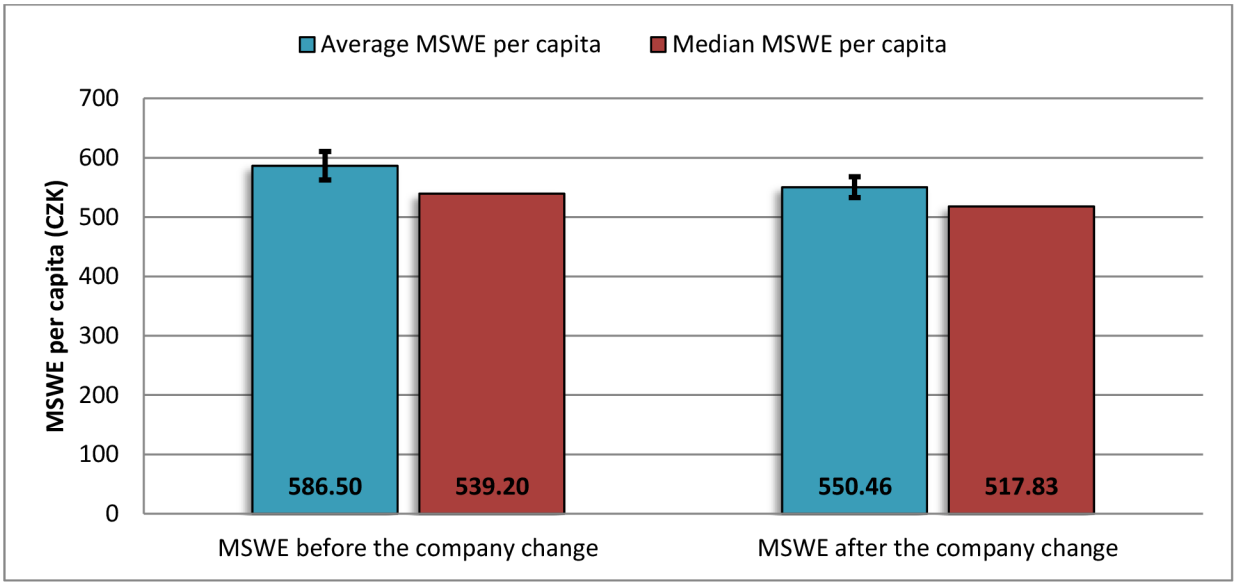
With the municipal data about the WM company change aligned to the same year 0, I calculated the relative differences in MSWE per capita between year 0 and year -1 and +1. Calculating these differences allows us to directly see the change of MSWE once the WM company change occurred.

Our sample of municipalities was also divided into the groups based on the type of change in terms of WM company ownership. As I mentioned, I differentiated between 4 types of ownership. After the data collection I have concluded that there are 5 most common situations with the WM company change in terms of ownership that are discussed later. After such distinction, each of the situations can be analyzed separately and compared to the other.

Results and Discussion

Figure 16 shows the difference between aggregated data from municipalities in year -1 and year 0 (after the municipality changed WM company). Provided data are MSWE per capita. The results show that once the municipality changed its WM company, average per capita expenditure decreased in the following year on average by 6% (median value was 4%). While this might not seem that significant, in terms of municipal finance where budgets are often very limited, even such relatively small change can make a difference. Moreover, in municipalities that perpetually extend their contract with the WM company, it is common that MSWE increase each year by few percent. Reduction in MSWE instead of a common increase thus represents even greater savings for the municipality.

Figure 16: Interannual change in MSWE after the change of the WM company (66 municipalities), standard errors for averages included



Source: own construction

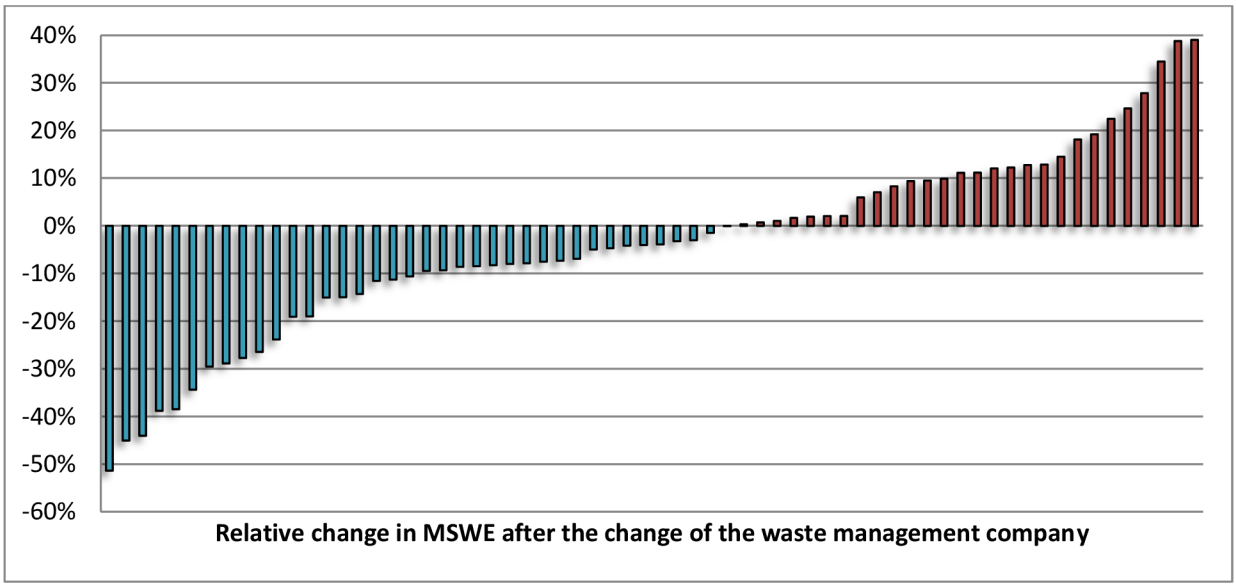
Figure 17 shows the relative interannual changes in MSWE of individual municipalities in the examined sample. In this figure we see that the change of the WM company does not always lead to the decrease in MSWE. There might be several reasons for that:

1) new WM company might provide a broader range of waste services, what logically results in higher costs. For instance the collection frequency might be increased, additional waste fractions might be separately collected, etc.

2) although being more expensive than before, the new company might still be actually cheaper than if the previous WM company was still in place. Jump increases in costs required by the original WM company have been mentioned by several municipal representatives as the important decision factor when changing the MSWM provider.

3) there might be some additional costs included in the reported MSWE by the municipality that coincidentally occurred in the same year as the WM company change. For instance, during this period many municipalities begun with separate collection of biowaste, which required purchasing composters or additional bins for the biowaste. Even though such purchases occur irregularly, technically they can count as current expenditure, leading to the increased reported MSWE in the given year, and thus possibly resulting in an overall increase of MSWE by several per cent.

Figure 17: Relative changes in MSWE of individual municipalities after the change of WM company (66 municipalities)

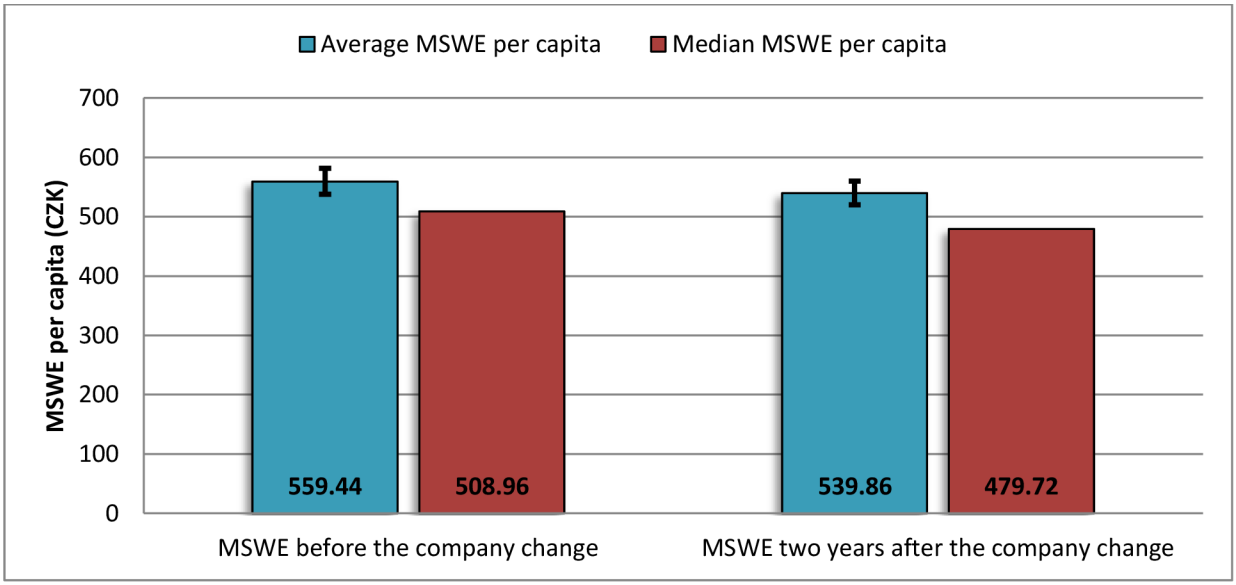


Source: own construction

Nevertheless, in the Figure 17 we see that majority of municipalities experienced a decrease in MSWE after they changed their WM company. Almost 30% of them report decrease in MSWE by up to 10%, while additional almost 30% report even higher MSWE reduction, with few municipalities saving even more than 40%. On the other hand, there are few municipalities that report increase in MSWE by over 30%, but based on my experience, such increase is very likely due to the one of the above mentioned reasons. Overall, half of the municipalities from the sample did not experience more than ±10% MSWE difference after the change.

Szymanski and Wilkins (1993) and Gomez-Lobo and Szymanski (2001) mention that while there might be great cost savings in the initial year, this advantage tends to diminish quickly in the following years, resulting again in higher costs and likely next public tender. In case of part of our sample I was able to obtain MSWE data also from the second year after the WM company change, and I present the results in Figure 18.

Figure 18: Comparison of MSWE before and two years after the change of the waste management company (52 municipalities), standard errors for averages included



Source: own construction

Figure 18 shows that two years after the company change, the savings still exist (on average 3.5% lower MSWE compared to the period before the change), but these are beginning to diminish, which is in accordance with the mentioned observation in other studies. With

respect to that, competitive tendering every few years might have the potential to keep MSWE down. On the other hand, any individual municipality needs to decide how often it should opt for the new tendering, as such action brings additional costs to the municipality.

Jacobsen et al. (2013) mention biannual tendering system in order to get the company with the best offer. One of the municipalities in our sample began to utilize such biannual tendering through electronic bidding application and was able to get much better contracts than before, although this is to a large extent caused by the rather poor starting condition of the WM provision in this particular municipality.

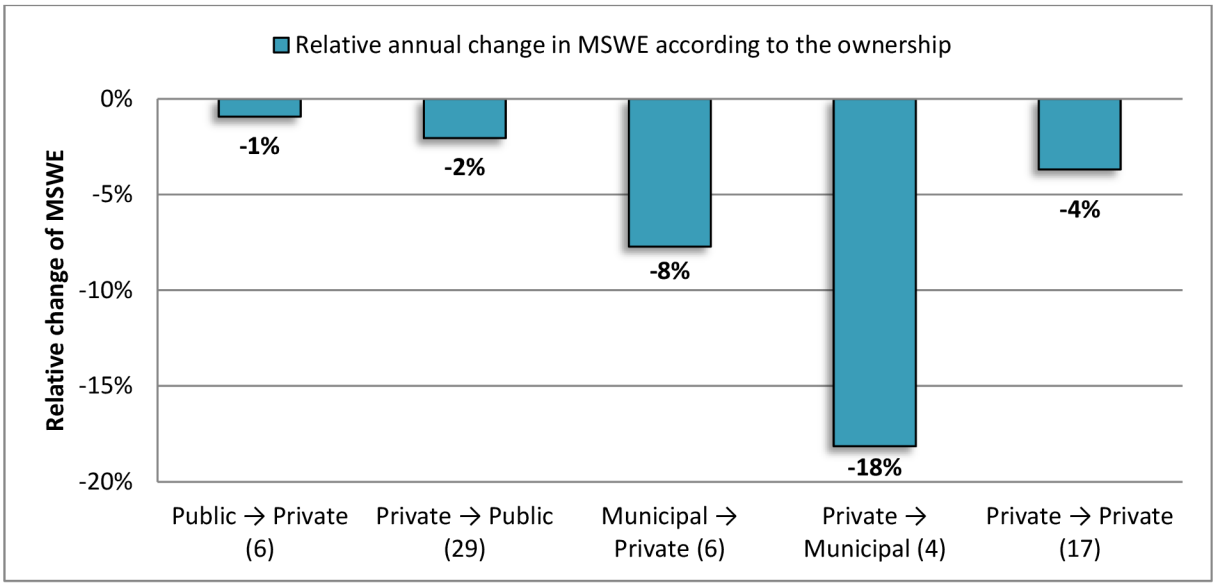
On the other hand, especially in case of smaller municipalities, costs associated with the tendering might be higher than the potential savings, and thus the change of the WM company will likely occur less frequently. The general suggestion here would then be to actively pursue public tendering as soon as the costs with the current WM company start to seem higher than they should be and the costs of the tender could be offset by the potential savings.

Finally in Figure 19 I show the changes in MSWE differentiated by the type of the company ownership before and after the WM company change, if such kind of change occurred at least 4 times. We can see that savings are present in case of any kind of change.

Slight savings are reported whether municipality changes from private WM company to public (in our conditions owned by an association of municipalities) WM company or vice versa. Larger savings seems to be possible if switching between private and municipal companies, but again, data suggest that this goes both ways. Based on that I cannot make a clear conclusion whether in terms of savings it is better to go with the private or public WM company. The conclusion that there is rather little difference in waste related costs between public and private companies is accordance with many authors (Domberger et al., 1986; Szymanski, 1996; Bel and Fageda, 2010), as well as the observation that much more important that ownership type of the company is the level of competition present (Gomez-

Lobo and Szymanski, 2001; Dijkgraaf and Gradus, 2007; Bel and Warner, 2008, Ochrana et al., 2007:99).

Figure 19: MSWE change according to the company ownership change (62 municipalities)



*I omitted 2 changes from public to mixed and 2 changes from mixed to private WM companies in this figure, as such changes are too few to show any relevant results
Source: own construction

However, if we look at the individual municipalities, in case of changing from private to public WM company there were highest amount of cases where MSWE increased. Thus even though there has been highest amount of changes from private to public companies (same trend was observed also by Gradus et al. (2014) in Netherlands), average savings in such cases were in our sample practically marginal. This is somehow in contradiction with Bel et al. (2014), who observed significant savings after municipalities switched from private WM companies to companies owned by a group of municipalities, or Bel and Costas (2006), who suggested that intermunicipal cooperation (which is in our case represented by a WM company owned by an association of municipalities) might be a good alternative for small municipalities with limited amount of potential external WM providers.

Observed increase of MSWE in multiple cases when switching to the public provider might partially explain mentioned disillusion of some municipal representatives expressed in the interviews after becoming a member of the association of the municipalities in order to utilize

MSWM service of the relevant public WM company. Based on that it is advisable for the municipality considering this kind of change to carefully examine whether the potential savings are truly there, compared to the other available options.

According to Massarutto (2007), even better results can be achieved when competitive tendering is used for dividing more specific activities along the WM value chain. However, based on my experience with the municipal representatives, such separate competing for specific activities in MSWM are very scarce. In my opinion the problem might also be the small average size of the municipality in the Czech Republic, where it does not make much economic sense for the WM companies to compete for only specific activities and thus dividing MSWM into distinct activities might be relevant only in the largest municipalities. But the results in those few municipalities where such separate tenders happen seem promising so far. Together with the stronger preference of the short-term contracts, suggested by Simões et al. (2012) this might become a good strategy for the municipalities in order to cut down MSWE and keep them there.

Partial conclusions

This study focused on the changes of costs in time, once the municipality switched to a different company providing WM services. Results show that a municipality is likely to benefit from such change and that majority of municipalities in our sample of 66 municipalities experienced decrease in their MSWE (on average by 6% in the first year after the change including the whole sample), in some cases even more than 20-30%. Compared to the previous situation, lower MSWE levels seem to hold also for the following year, although savings tend to diminish later.

On the other hand, in some municipalities the costs increased, but based on my experience this was likely caused by other factors, namely the extension of activities included in the provided WM service. In other cases, where municipalities experienced MSWE increase after the WM company change, was this increase often notably less steep than with the previous provider, what can be perceived as an actual saving compared to the situation without change.

Finally I examined the differences in MSWE when switching from public to private MSWM providers and vice versa, but did not find any significant patterns. It seems that, in accordance with other authors, it does not matter much whether the WM provider is public or private, but whether the municipality is willing to regularly engage in competitive tendering. By doing this the municipality seems to be most likely to get best available services at reasonable costs.

The validity of the results might be questioned, as the data used in the analysis are solely from one region in the Czech Republic. This is true, it is a limitation of this study. However, data for municipalities from other regions are not available and it would require additional collection that, especially considering the fact how fragmented Czech municipalities are, requires significant amount of time. But in my opinion even results from a territorially limited sample represent useful findings about the important efficiency factors in the municipal waste management. It is possible that in some regions there are some additional factors that might cause a bit different results, but the factors that I have included in this study (ownership nature of the WM company and the presence of competition) in my opinion apply generally in the whole country, plus the absolute size of the sample (over 60) municipalities suggest that the results could be generalized to a certain extent also to the whole Czech Republic.

4.4 Discussion of the findings and suggestions for practical applications

Throughout this chapter I have examined several factors influencing MSWM efficiency that have been identified earlier using either 2SDEA or in the relevant literature, and seem to play an important role in the overall performance of MSWM. These findings include positive effect of improved convenience of the waste separation on the municipal waste generation and the amount of separated waste, strong positive effect of implementing incentives in MSWM, several interesting observations regarding relationship of age structure and MSW generation and expenditures, and finally the importance of available competition in the field of MSWM, regardless of the ownership nature of the WM company. Incentives and ownership arrangements have also been identified as important factors in MSWM area by Simões and Marques (2012), together with the effects of economies of scale and benchmarking. However, in related research by Soukopová et al. (2014) we did not find economies of scale to be

present in MSWM area in the Czech Republic. Benchmarking in MSWM was, according to the interviews with the municipal representatives in our sample, also very rarely used, if at all.

Convenience of the waste separation was identified as a key factor when trying to improve MSWM. This can be translated into the either availability of the separation options, such as presence of drop-off sites or HWRC, or the distance to the nearest waste separation site. Both of these work with the necessary required time in order to separate waste, with logically less effort needed leading to higher waste separation rates. I specifically examined how well municipalities separate paper and plastics in scenarios when they have basic drop-off sites, kerbside collection of recyclable waste fractions, or their combination. According to the findings, drop-off sites produce on average approximately 7.7% waste separation while kerbside collection produces 9.7%. While this might not seem to be much, I stress that only recyclable waste fractions paper and cardboard and plastics were considered, thus total separation level would be notably higher. Density of drop-off sites was also examined with the finding that one additional drop-off site per hectare increases waste separation by 3.9%. But with the average density of just 0.29 drop-off sites per hectare in the sample this might not be that much important in the practice. However, kerbside collection seems to have a significant effect on the waste separation. All in all it should not be surprising, as it represents likely the most convenient option for waste separation. Unlike with the drop-off sites, people do not need to carry their separated waste anywhere, they just put it in front of their property at scheduled times for the pickup. Compared to the (in the Czech Republic) standard waste separation through drop-off sites it increases the waste separation level by 20%. Moreover, if implemented appropriately, kerbside collection can significantly reduce the problems associated with the drop-off sites. These include for instance the requirements for a well accessible public space for the containers placement together with the frequent NIMBY effect from the locals. On the other hand, kerbside collection might be difficult to implement if the prevailing housing structure consists of apartment buildings, or the requirement to store the separated waste fractions inside one's household or at one's property in between the pickups, what might not be acceptable for some people. Still, when trying to increase waste separation level in the municipality, kerbside collection seems like an appropriate solution, where the benefits from higher waste separation (and subsequently lower mixed residual waste generation) should outweigh the extra costs associated with it. In cases when kerbside

collection almost fully replaced drop-off sites it even resulted in comparable or lower expenditures for the municipality, further stressing the viability of such solution in MSWM.

Incentive programs related to the waste separation produced very strong results with respect to the achieved waste separation rate. In the model with drop-off sites and kerbside collection adding an incentive program practically doubled the amount of separated waste. A typical practical application of an incentive program is in the form of a PAYT scheme with variable charges based on individual household's waste generation. In Czech Republic mostly in adjusted (reversed) form in order to reward those who separate more waste. In my opinion such system has multiple advantages, as people are less motivated to exhibit certain kinds of unwanted behavior usually related with standard PAYT systems. People in general seem to prefer systems where they get rewarded instead of punished, even if the final result in terms of paid fees is practically the same. On the other hand, providing rewards based on the waste separation requires a more complex planning and possibly other necessary measures. In case of the Czech Republic, incentives in WM are usually connected with kerbside collection, where adding a sticker with the barcode allows WM company to clearly connect individual household with the amount of waste it had separated. However, in the end it is up to the decision makers (municipal representatives) what they prefer, and most importantly how well are they able to communicate the benefits of the new measures and ways how they work. Again as was mentioned above, depending on the specifications of the incentive system, it might lead both to the increased waste separation and the lower overall MSWE.

Age structure of the municipality has been in this thesis identified as an important proxy for predicting both MSW generation and MSWE. Importance of such finding lies in the availability of the data regarding municipal population. Presented models showed differences between waste and expenditures connected with the waste behavior of 10 various age cohorts in the sample of municipalities. An interesting and novel finding was that people in the 60-69 age group tend to generate notable amounts of MSW compared to other age groups, subsequently resulting in much higher MSWE attributed to this age group. The proposed theory behind this is that people in this age group are usually around the time of commencing retirement, what is connected with significant adjustments of their households in order to prepare for their retirement. Such process naturally includes generation of large amount of

waste by discard many items from their households with no expected use in future. In case of estimated models explaining waste separation, notable difference was identified between various age groups. Young people together with the elderly were identified as those separating the most, while people of middle age were identified as those separating the least. Comparable results were obtained in the models explaining MSW generation. Such findings suggest that middle aged people represents the largest potential for improving MSWM results in terms of waste separation and minimization, and the campaigns focused towards these issues should be aimed primarily at them, as the other age categories seem to be performing well already. Alternatively, municipal representatives could try to adjust the current charging systems for MSWM services in order to take into account the age factor and vary the height of local taxes (waste charges) according to the citizen age. This might be perceived as being more just than the existing waste disposal charging system, and could distantly evoke a kind of a PAYT charging scheme. However, practical enforcement of such change instead of the widely used flat fee per capita seems to me at the moment as politically very challenging.

Competition presence in MSWM represents, according to the obtained results, another important factor in economic performance of MSWM. The worst case seems to be the one where municipality stays with one WM provider, does not look for any other and simply perpetually extends the current contract with continually increasing costs due to both inflation and higher service charge by the WM company. I understand that for some remote municipalities this might be in fact the only available option, but in case of majority of the municipalities a regular engaging in WM services tendering should produce benefits in form of lower MSWE. In the analyzed sample majority of the municipalities that changed WM company report saving in the following year, on average by 6% if including the whole sample. MSWE savings seem to hold even in the second year after the company change. And even in some cases where MSWE did not decrease, new WM provider often brought additional services or improved the quality of the current ones, which might be worth the extra costs. As usual with the competition, people as the final consumers are often those who benefit most from such situations. Besides impact of the company change to MSWE, I also examined the types of ownership of the WM companies participating in the change. The literature dealing with the question of whether the public services should be provided by public companies or contracted out to the private ones mostly does not provide a consensus

on the matter. This holds also for our case, when it seems that it does not matter whether the WM company has public or private ownership, but whether there is sufficient competition present at the market. The results show that it actually does not matter whether the municipality changes WM provider from private to public or vice versa – what matters is the fact that the change itself occurred. Subsequent savings in MSWE were reported in either case. The municipal representatives should therefore be encouraged to actively pursue regular public tendering of WM services. Practical experience and foreign literature suggest public tenders every 2-3 years. Also, even if the WM company does not actually change, the new contract should at least lead to a more reasonable MSWE levels and reflect currently available options at the MSWM market.

There are generally two main limitations that I can see in provided studies of selected factor influencing efficiency. First one is the everpresent possibility that there are some additional significant factors that influenced the observed results but were not included in the analysis. This is generally true for practically any models that do not have coefficient of determination close to unity. But in my case my goal was not the complete explanation of the municipal performance, but rather the examination of selected efficiency factors that might be potentially important. And as long as they were identified as statistically significant, the objective was met and the conclusion about these specific factors could have been drawn. This leads us to the second limitation, which lies in the availability of data. In an ideal situation, all thinkable data that could be related to the municipal waste management would be available for a long time period and for all municipalities. Unfortunately, this is far from true, and I had to rely on selected variables that are available in the central public databases and the data I was able to collect. Therefore, strictly speaking, my results should be relevant only for the limited sample and factors that were included in the examination. However, due to the used sizes of the samples and sometimes also multiple years, the results should also have general validity to a certain extent. But I am aware that especially in uncontrolled real world there are usually many factors that contribute to the final performance of (not just) municipal waste management, including many municipality-unique and qualitative ones that were not considered in the analysis. The more I dive into the municipal waste management, the less I seem to know about this complex issue.

CONCLUSIONS

This thesis was focused on the municipal solid waste management and the related factors that influence its efficiency. The area of waste management was chosen specifically, as it represents an interference of environmental protection and public service. As was shown in the first chapter, waste management represents the most important area of environmental protection expenditure in the Czech Republic, and so is the case in many individual municipalities. Efficiency improvements in this area thus can have significant and positive effect on the municipal budgets and on the environment as well.

The objectives of this thesis were to 1) describe situation in municipal solid waste management in a selected Czech region; and 2) identify relevant efficiency factors in this region using both collected data and available literature, and based on further analysis provide policy suggestions for improving municipal waste management in the region.

First, I have collected relevant literature in order to identify potential factors influencing efficiency of municipal waste management. Next I have collected data from more than 500 municipalities in the South Moravian Region and spoke directly with the municipal representatives about the municipal waste management in their municipalities and about what they consider important in this area. Most interesting were probably the numerous qualitative findings from individual municipalities that show how much variety can exist among the municipalities in the area of waste management and that there is no one-size-fits-all solution. This data collection provided me with ideas which factor could be potentially important when dealing with municipal solid waste efficiency and which of them to focus on in further analyses. Based on the analysis of the collected data using Data Envelopment Analysis I have chosen to further examine convenience and incentives factor, and based on the literature study I have chosen to examine factors of age structure of the municipality and the type of waste management company ownership including switching between them by the municipalities.

Convenience of the waste separation from the perspective of municipal citizens proved to be a very important factor in their decision to separate waste. I note here that higher waste

separation is typically connected with lower mixed residual waste generation. This is an important note, as separated waste acts more like a resource and often can be traded in the relevant market for a profit, while residual waste does not have that much further use and requires significant costs in order to be treated appropriately. Availability of the infrastructure such as drop-off points and waste recycling centers is a necessary but not sufficient condition for improved waste separation. Results show that even more important might be the perceived convenience of the whole process, usually (and also in our case) represented by the distance to the closest relevant waste separation site. Less effort needed in order to separate translates into higher separation rates of municipal waste. The most convenient solution from this perspective is a kerbside collection, even though in might not be possible to always implement this system of waste separation. These limitations exist especially in cases where there is no simple way how to match generated waste and the household that generated it – typically in areas with multi family dwelling such as apartment buildings. In these cases is the waste separation through standard densely located drop-off sites accompanied by an occasional waste recycling center probably the best available option.

Incentives proved to have probably the strongest impact on the waste separation levels in municipalities, and the inclusion of such measures often doubled the previous waste separation values. Incentive systems in the municipal waste management can be very well paired with kerbside collection, and every municipality in the sample that implemented both of these measures reported very high waste separation levels compared to the other municipalities. However, in the end it is up to the individual municipality and its representatives to devote necessary time and effort to developing an appropriate system that takes into account unique characteristics of the given municipality. Here it definitely holds that one size does not fit all, and what works very well in one municipality might not work at all in the other. Very important thing here is to appropriately communicate the benefits of the new system and how it works. If done correctly, people will do the rest.

Age structure of the municipality can act as a proxy for both waste generation and waste expenditure in the municipality, as both these values are naturally related. Our models showed notable differences between waste behaviors of different age groups. The most important findings of this part were probably very high levels of waste generation of the 60-69 age

group, which is in our opinion caused by one's preparation for the retirement. On the other hand, young people tend to produce among the least waste, together with highest waste separation tendencies. Such observations might be utilized in a better design of the waste related campaigns that should focus more on the middle aged people, where the potential benefits are highest, instead of young people, where relatively good results have already been achieved.

Finally, change of company providing municipal waste management seems to effects related municipal expenditure generally in a positive way. Results show that majority of municipalities did benefit from such change and it is suggested to make such public tender every 2-3 years in order get best available prices and levels of service. Even though this might not be easily applicable in all municipalities, those that identify at least some competition around should not be reluctant to change their waste provider, as it can often lead to the improved waste management in the municipality. And even if they keep the current provider, public tendering might at least result in better prices and higher quality of the provided service, if the current provider wants to stay competitive with the others entering the tender. Besides that I have also examined whether there is any difference in the type of the waste company ownership and based on the results I conclude that there does not seem to be anything like that. Improvements after the change of the company happened regardless of whether the municipality switched from private to public company or vice versa. Therefore I conclude that it is not the ownership of the company that matters, but the presence of competition among these companies. With sufficiently competitive environment and the willingness of the municipalities to change their waste provider, should some better offer occur, every waste company regardless of the ownership has to stay competitive in order to survive. A by-product of such situation should be then a provision of an efficient municipal solid waste management.

Due to the employed methods the validity of the results is limited by the used data and sample of municipalities, and there is always a possibility that some important factor was omitted from the analysis. Nevertheless, the used samples were in majority cases relatively large and the objective was to examine the effects of the specified potential efficiency factors, of which

several proved to be statistically significant. Therefore the results should to a certain extent valid for the whole Czech Republic as well.

Nevertheless, in my opinion some policy recommendations could be drawn from the provided results. First of all, convenience seems to play a key role for the people when deciding whether to separate. Thus the proper infrastructure needs to be established. However, infrastructure sometimes is not sufficient, and other measures, like for instance incentive programs focused on waste separation could be employed. Results show that with proper setting such systems are able to both perform better economically and environmentally. Besides that municipalities should pay closer attention to the inner factors like, for instance, examined age structure. Results show that there are notable differences between waste related behavior of various age groups and the municipal approach should reflect that, in order not to waste money, and instead use them where they can make the most difference. Least but not last, role of the competition show both in this study and multiple other to be the key factor when trying to secure best available conditions for municipal waste management provision. Municipalities therefore should take active part and regularly pursue competitive tendering and not become accustomed with the current solution for too long. Results also show that it actually should not matter whether the waste management is provided by the public or private company, as long as the market is competitive enough.

LITERATURE

[1] Abbott, A., Nandeibam, S. & O'Shea, L. (2011). Explaining the variation in household recycling rates across the UK. *Ecological Economics*. 70(11), 2214-2223. https://dx.doi.org/10.1016/j.ecolecon.2011.06.028.

[2] Afriat, S. N. (1972). Efficiency Estimation of Production Functions. *International Economic Review*, 13(3), 568-598. https://doi.org/10.2307/2525845.

[3] Afonso, A. & Fernandes, S. (2008). Assessing and explaining the relative efficiency of local government. *The Journal of Socio-Economics*, 37, 1946-1979. https://doi.org/10.1016/j.socec.2007.03.007.

[4] Aigner, D. J. & Chu, S. F. (1968). On Estimating the Industry Production Function. *The American Economic Review*, 58, 826-839. www.jstor.org/stable/1815535.

[5] Aigner, D. J., Lovell, C. A. K. & Schmidt, P. (1977). Formulation and Estimation of Stochastic Production Function Models. *Journal of Econometrics*, 6, 21-37. https://doi.org/10.1016/0304-4076(77)90052-5.

[6] Allers, M. A. & Hoeben, C. (2010). Effects of unit-based garbage pricing: a differences-in-differences approach. *Environmental and Resource Economics*. 45(3), 405-428. https://dx.doi.org/10.1007/s10640-009-9320-6.

[7] Ando, A. W. & Gosselin, A. Y. (2005). Recycling in multifamily dwellings: does convenience matter? *Economic Inquiry*. 43(2), 426-438. https://dx.doi.org/10.1093/ei/cbi029.

[8] Ashenmiller, B. (2011). The effect of bottle laws on income: new empirical results. *The American Economic Review*, 101(3), 60-64. https://doi.org/10.1257/aer.101.3.60.

[9] Ayalon, O., Brody, S. & Schechter, M. (2013). Household waste generation, recycling and prevention. *OECD Studies on Environmental Policy and Household Behaviour Greening Household Behaviour: Overview from the 2011 Survey*, 219-245. https://dx.doi.org/10.1787/9789264214651-11-en.

[10] Bae, S. (2010). Public versus private delivery of municipal solid waste services: The case of North Carolina. *Contemporary Economic Policy*, 28(3), 414-428. https://doi.org/10.1111/j.1465-7287.2009.00180.x.

[11] Bakoš, E., Soukopová, J. & Kaplanová, B. (2009). Porovnání vykazovaných environmentálních dat se zaměřením na úroveň municipalit. *In Účetnictví a reporting udržitelného rozvoje na mikroekonomické a makroekonomické úrovni*, Praha: Linde, 79-85, ISBN 978-80-86131-82-5.

[12] Bandara, N. J., Hettiaratchi, J. P. A., Wirasinghe, S. C. & Pilapiiya, S. (2007). Relation of waste generation and composition to socio-economic factors: a case study. *Environmental Monitoring and Assessment*, 135(1-3), 31–39. https://doi.org/10.1007/s10661-007-9705-3.

[13] Banker, R. D., Charnes, A. & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30(9), 1078-1092. https://doi.org/10.1287/mnsc.30.9.1078.

[14] Barr, S., Ford, N. J. & Gilg, A. W. (2003). Attitudes towards recycling household waste in Exeter, Devon: quantitative and qualitative approaches. *Local Environment: The International Journal of Justice and Sustainability*, 8(4), 407-421. https://dx.doi.org/10.1080/13549830306667.

[15] Battese, G. E. & Corra, G. S. (1977). Estimation of a Production Frontier Model: With Applications to the Pastoral Zone of Eastern Australia. *Australian Journal of Agricultural Economics*, 21, 169-179. https://doi.org/10.1111/j.1467-8489.1977.tb00204.x.

[16] Beigl, P., Lebersorger, S. & Salhofer, S. (2008). Modelling municipal solid waste generation: A review. *Waste Management*, 28 (1), 200–214. https://dx.doi.org/10.1016/j.wasman.2006.12.011.

[17] Beigl, P., Wassermann, G., Schneider, F. & Salhofer, S. (2004). Forecasting municipal solid waste generation in major European cities. *In iEMSs 2004 International Congress: Complexity and Integrated Resources Management, Osnabruck, Germany*. https://scholarsarchive.byu.edu/iemssconference/2004/all/83/.

[18] Bel, G. & Costas, A. (2006). Do public sector reforms get rusty? Local privatization in Spain. *The Journal of Policy Reform*, 9(1), 1-24. https://doi.org/10.1080/13841280500513084.

[19] Bel, G. & Fageda, X. (2010). Empirical analysis of solid management waste costs: Some evidence from Galicia, Spain. *Resources, Conservation and Recycling*, 54(3), 187-193. https://doi.org/10.1016/j.resconrec.2009.07.015.

[20] Bel, G., Fageda, X. & Mur, M. (2014). Does Cooperation Reduce Service Delivery Costs? Evidence from Residential Solid Waste Services. *Journal of Public Administration Research and Theory*, 24(1), 85–107. https://doi.org/10.1093/jopart/mus059.

[21] Bel, G., Fageda, X. & Warner, M. E. (2010). Is private production of public services cheaper than public production? A meta-regression analysis of solid waste and water services. *Journal of Policy Analysis and Management*, 29(3), 553-577. https://doi.org/10.1002/pam.20509.

[22] Bel, G., & Mur, M. (2009). Intermunicipal cooperation, privatization and waste management costs: Evidence from rural municipalities. *Waste Management*, 29(10), 2772-2778. https://doi.org/10.1016/j.wasman.2009.06.002.

[23] Bel, G. & Warner, M. (2008). Does privatization of solid waste and water services reduce costs? A review of empirical studies. *Resources, Conservation and Recycling*, 52(12), 1337-1348. https://doi.org/10.1016/j.resconrec.2008.07.014.

[24] Belton, V., Crowe, D. V., Matthews, R. & Scott, S. (1994). A survey of public attitudes to recycling in Glasgow (UK). *Waste Management & Research*, 12(4), 351-367. https://dx.doi.org/10.1006/wmre.1994.1024.

[25] Benítez, S. O., Lozano-Olvera, G., Morelos, R. A. & Vega, C. A. D. (2008). Mathematical modeling to predict residential solid waste generation. *Waste Management*, 28(S1), S7–S13. https://doi.org/10.1016/j.wasman.2008.03.020.

[26] Benito-López, B., del Rocio Moreno-Enguix, M. & Solana-Ibañez, J. (2011). Determinants of efficiency in the provision of municipal street-cleaning and refuse collection services. *Waste Management*, 31(6), 1099-1108. https://doi.org/10.1016/j.wasman.2011.01.019.

[27] Bilitewski, B. (2008). From traditional to modern fee systems. *Waste Management*, 28(12), 2760-2766. https://dx.doi.org/10.1016/j.wasman.2008.03.032.

[28] Bosch, N., Pedraja, F. & Suárez-Pandiello, J. (2000). Measuring the Efficiency of Spanish Municipal Refuse Collection Services. *Local Government Studies*, 26(3), 71-90. https://doi.org/10.1080/03003930008434000.

[29] Brown, D. P. (2015). Garbage: How population, landmass, and development interact with culture in the production of waste. *Resources, Conservation and Recycling*. 98, 41-54. https://doi.org/10.1016/j.resconrec.2015.02.012.

[30] Bucciol, A., Montinari, N. & Piovesan, M. (2015). Do not trash the incentive! Monetary incentives and waste sorting. *The Scandinavian Journal of Economics*, 117(4), 1204-1229. https://dx.doi.org/10.1111/sjoe.12122.

[31] Byrne, S. & O'Regan, B. (2014). Attitudes and actions towards recycling behaviours in the Limerick, Ireland region. *Resources, Conservation and Recycling*, 87, 89-96. https://dx.doi.org/10.1016/j.resconrec.2014.03.001.

[32] CENIA (2017). *Celkové výdaje na ochranu životního prostředí*. https://issar.cenia.cz/prehled-klicovych-indikatoru-podle-hlavnich-temat/financovani-ochrany-zivotniho-prostredi/celkove-vydaje-na-ochranu-zivotniho-prostredi/.

[33] Charnes, A., Cooper, W. W. & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429-444. https://doi.org/10.1016/0377-2217(78)90138-8.

[34] Chen, M. F. & Tung, P. J. (2010). The moderating effect of perceived lack of facilities on consumers' recycling intentions. *Environment and Behavior*, 42(6), 824-844. https://dx.doi.org/10.1177/0013916509352833.

[35] Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. & Battese, G. E. (2005). *An Introduction to Efficiency and Productivity Analysis*. New York: Springer, 349 p. ISBN 978-0-387-25895-9. https://dx.doi.org/10.1007/b136381.

[36] Coli, M., Nissi, E. & Rapposelli, A. (2011). Monitoring environmental efficiency: An application to Italian provinces. *Environmental Modelling & Software*, 26(1), 38-43. https://doi.org/10.1016/j.envsoft.2010.07.004.

[37] Cook, W. D. & Seiford, L. M. (2009). Data Envelopment Analysis (DEA) – Thirty Years On. *European Journal of Operational Research*, 192(1), 1-17. https://doi.org/10.1016/j.ejor.2008.01.032.

[38] Cooper, W. W., Seiford, L. M. & Tone, K. (2006). *Introduction to Data Envelopment Analysis and Its Uses*. Springer-Verlag, 354 p. ISBN 978-0-387-28580-1. https://doi.org/10.1007/0-387-29122-9.

[39] CZSO (2018). *Czech Statistical Office – various data*. https://www.czso.cz.

[40] Dahlén, L. & Lagerkvist, A. (2010). Evaluation of recycling programmes in household waste collection systems. *Waste Management & Research* 28(7), 577-586. https://dx.doi.org/10.1177/0734242X09341193.

[41] Dahlén, L., Vukicevic, S., Meijer, J. E. & Lagerkvist, A. (2007). Comparison of different collection systems for sorted household waste in Sweden. *Waste Management*. 27(10), 1298-1305. https://dx.doi.org/10.1016/j.wasman.2006.06.016.

[42] Daraio, C. & Simar, L. (2005). Introducing environmental variables in nonparametric frontier models: a probabilistic approach. *Journal of productivity analysis*, 24(1), 93-121. https://doi.org/10.1007/s11123-005-3042-8.

[43] Daskalopoulos, E., Badr, O. & Probert, S. D. (1998). Municipal solid waste: a prediction methodology for the generation rate and composition in the European Union countries and the United States of America. *Resources, Conservation and Recycling*, 24(2), 155-166. https://doi.org/10.1016/S0921-3449(98)00032-9.

[44] De Jaeger, S., Eyckmans, J., Rogge, N. & Van Puyenbroeck, T. (2011). Wasteful waste-reducing policies? The impact of waste reduction policy instruments on collection and processing costs of municipal solid waste. *Waste Management*, 31(7), 1429-1440. https://doi.org/10.1016/j.wasman.2011.02.021.

[45] Debreu, G. (1951). The Coefficient of Resource Utilizations. *Econometrica*, 19(3), 273-292. https://dx.doi.org/10.2307/1906814.

[46] Dennison, G. J., Dodd, V. A. & Whelan, B. (1996). A socio-economic based survey of household waste characteristics in the city of Dublin, Ireland. II. Waste quantities. *Resources, Conservation and Recycling*, 17(3), 245–257. https://doi.org/10.1016/0921-3449(96)01155-X.

[47] Derksen, L. & Gartrell, J. (1993). The social context of recycling. *American Sociological Review*, 58(3), 434-442. https://dx.doi.org/10.2307/2095910.

[48] Dijkgraaf, E. & Gradus, R. (2007). Collusion in the Dutch waste collection market. *Local Government Studies*, 33(4), 573-588. https://doi.org/10.1080/03003930701417601.

[49] Dijkgraaf, E. & Gradus, R. (2004). Cost savings in unit-based pricing of household waste: The case of The Netherlands. *Resource and Energy Economics*, 26(4), 353-371. https://dx.doi.org/10.1016/j.reseneeco.2004.01.001.

[50] Dijkgraaf, E. & Gradus, R. (2003). Cost savings of contracting out refuse collection. *Empirica*, 30(2), 149-161. https://doi.org/10.1023/A:1024175730230.

[51] Domberger, S., Meadowcroft, S. A. & Thompson, D. J. (1986). Competitive tendering and efficiency: the case of refuse collection. *Fiscal Studies*, 7(4), 69-87. https://doi.org/10.1111/j.1475-5890.1986.tb00530.x.

[52] Domina, T. & Koch, K. (2002). Convenience and Frequency of Recycling Implications for Including Textiles in Curbside Recycling Programs. *Environment and Behavior*, 34(2), 216-238. https://doi.org/10.1177/0013916502342004.

[53] Dubin, J. A. & Navarro, P. (1988). How markets for impure public goods organize: the case of household refuse collection. *Journal of Law, Economics & Organization*, 4(2), 217-241. http://www.jstor.org/stable/764922.

[54] Dyson, R. G., Allen, R., Camanho, A. S., Podinovski, V. V., Sarrico, C. S. & Shale, E. A. (2001). Pitfalls and protocols in DEA. *European Journal of Operational Research*, 132(2), 245-259. https://doi.org/10.1016/S0377-2217(00)00149-1.

[55] Dyson, B. & Chang, N. B. (2005). Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modelling. *Waste Management*, 25(7), 669-679. https://doi.org/10.1016/j.wasman.2004.10.005.

[56] Emrouznejad, A., Parker, B. R. & Tavares, G. (2008). Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. *Journal of Socio-Economic Planning Science*, 42(3), 151-157. https://doi.org/10.1016/j.seps.2007.07.002.

[57] Emrouznejad, A. & Yang, G. L. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. *Socio-Economic Planning Sciences*, 61, 4-8. https://doi.org/10.1016/j.seps.2017.01.008.

[58] Eurostat (2015). *Municipal waste generation and treatment, by type of treatment method*. ec.europa.eu/eurostat/web/products-datasets/-/tsdpc240.

[59] Farrell, M. J. (1957). The Measurement of Technical Efficiency. *Journal of Royal Statistical Society*, Series A, General, 120, Part 3, 253-281. https://dx.doi.org/10.2307/2343100.

[60] Fiala, P. (2007). Analýza efektivnosti odpadového hospodářství českých obcí metodou DEA. *In Šauer, P. (ed.) Příspěvky k metodologii ex-post analýz v politice životního prostředí II*. Praha: SEPTIMtisk, 87-105, ISBN 978-80-904032-0-8.

[61] Folz, D. H. (1999). Municipal recycling performance: A public sector environmental success story. *Public Administration Review*, 59(4), 336–345. https://dx.doi.org/10.2307/3110116.

[62] Folz, D. H. (1991). Recycling program design, management, and participation: a national survey of municipal experience. *Public Administration Review*, 51(3), 222-231. https://dx.doi.org/10.2307/976946.

[63] Førsund, F. R. (2018). Economic interpretations of DEA. *Socio-Economic Planning Sciences*, 61, 9-15. https://doi.org/10.1016/j.seps.2017.03.004.

[64] Førsund, F. R. & Sarafoglou, N. (2002). On the Origins of Data Envelopment Analysis. *Journal of Productivity Analysis*, 17, 23-40. https://doi.org/10.1023/A:1013519902012.

[65] Fried, H. O., Lovell, C. A. K. & Schmidt, S. S. (eds.) (2008). *The Measurement of Productive Efficiency and Productivity Growth*. Oxford University Press, 638 p., ISBN 978-0-19-518352-8. http://dx.doi.org/10.1093/acprof:oso/9780195183528.001.0001.

[66] Fullerton, D. & Kinnaman, T. C. (1996). Household responses to pricing garbage by the bag. *The American Economic Review*, 86(4), 971-984. http://www.jstor.org/stable/2118314.

[67] García-Sánchez, I. M. (2008). The performance of Spanish solid waste collection. *Waste Management & Research*, 26(4), 327-336. https://doi.org/10.1177/0734242X07081486.

[68] Gattoufi, S., Oral, M. & Reisman, A. (2004a). A taxonomy for data envelopment analysis, *Socio-Economic Planning Sciences*, 38(2-3), 141-158. https://doi.org/10.1016/S0038-0121(03)00022-3.

[69] Gattoufi, S., Oral, M. & Reisman, A. (2004b). Data Envelopment Analysis Literature: A Bibliography Update (1951-2001). *Socio-Economic Planning Sciences*, 38(2-3), 159-229. http://dx.doi.org/10.1016/S0038-0121(03)00023-5.

[70] Gellynck, X., Jacobsen, R. & Verhelst, P. (2011). Identifying the key factors in increasing recycling and reducing residual household waste: A case study of the Flemish region of Belgium. *Journal of Environmental Management*, 92(10) , 2683-2690. https://doi.org/10.1016/j.jenvman.2011.06.006.

[71] Gillespie, R. & Bennett, J. (2011). Willingness to pay for kerbside recycling the Brisbane Region, *EERH Research Report No. 97*, Available at crawford.anu.edu.au/research_units/eerh/pdf/EERH_RR97.pdf.

[72] Gomez-Lobo, A. & Szymanski, S. (2001). A law of large numbers: bidding and compulsory competitive tendering for refuse collection contracts. *Review of Industrial Organization*, 18(1), 105-113. https://doi.org/10.1023/A:1026545306923.

[73] Gonzáles-Torre, P. L. & Adenso-Díaz, B. (2005). Influence of distance on the motivation and frequency of household recycling. *Waste Management*, 25(1), 15-23. https://dx.doi.org/10.1016/j.wasman.2004.08.007.

[74] Gradus, R., Dijkgraaf, E. & Wassenaar, M. (2014). Understanding Mixed Forms of Refuse Collection, Privatization, and Its Reverse in the Netherlands. *International Public Management Journal*, 17(3), 328-343. https://doi.org/10.1080/10967494.2014.935237.

[75] Greene, W. H. (2008). The Econometric Approach to Efficiency Analysis. *In Fried, H. O. et al. (eds.) The Measurement of Productive Efficiency and Productivity Growth*. Oxford University Press, 92-250, ISBN 978-0-19-518352-8. http://dx.doi.org/10.1093/acprof:oso/9780195183528.001.0001.

[76] Guerrero, L. A., Maas, G.,& Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste management*, 33(1), 220-232. https://doi.org/10.1016/j.wasman.2012.09.008.

[77] Guerrini, A., Carvalho, P., Romano, G., Marques, R. C. & Leardini, C. (2017). Assessing efficiency drivers in municipal solid waste collection services through a non-

parametric method. *Journal of Cleaner Production*, 147, 431-441. https://doi.org/10.1016/j.jclepro.2017.01.079.

[78] Hage, O. & Söderholm, P. (2008). An econometric analysis of regional differences in household waste collection: the case of plastic packaging waste in Sweden. *Waste Management*, 28(10), 1720-1731. https://doi.org/10.1016/j.wasman.2007.08.022.

[79] Hage, O., Söderholm, P. & Berglund, C. (2009). Norms and economic motivation in household recycling: empirical evidence from Sweden. *Resources, Conservation and Recycling*, 53(3), 155-165. https://dx.doi.org/10.1016/j.resconrec.2008.11.003.

[80] Halvorsen, B. (2012). Effects of norms and policy incentives on household recycling: An international comparison. *Resources, Conservation and Recycling*, 67, 18-26. https://dx.doi.org/10.1016/j.resconrec.2012.06.008.

[81] Hillman, A. (2009). *Public Finance and Public Policy: Responsibilities and Limitations of Government*. Cambridge University Press, 859 p. ISBN 978-0-521-49426-7. https://doi.org/10.1017/CBO9780511813788.

[82] Hockett, D., Lober, D. J. & Pilgrim, K. (1995). Determinants of per capita municipal solid waste generation in the Southeastern United States. *Journal of Environmental Management*, 45(3), 205-217. https://doi.org/10.1006/jema.1995.0069.

[83] Hoff, A. (2007). Second stage DEA: Comparison of approaches for modelling the DEA score. *European Journal of Operational Research*, 181(1), 425-435. https://doi.org/10.1016/j.ejor.2006.05.019.

[84] Honma, S. (2014). Environmental and Economic Efficiencies in the Asia-Pacific Region, *Journal of Asia-Pacific Business*, 15(2), 122-135. https://doi.org/10.1080/10599231.2014.904185.

[85] Hornik, J., Cherian, J., Madansky, M. & Narayana, C. (1995). Determinants of recycling behavior: A synthesis of research results. *The Journal of Socio-Economics*, 24(1), 105-127. https://doi.org/10.1016/1053-5357(95)90032-2.

[86] Hřebíček, J., Kalina, J. & Soukopová, J. (2013). Integrated economic model of waste management: Case study for South Moravia region. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(4), 917-922. https://doi.org/10.11118/actaun201361040917.

[87] Hřebíček, J. & Soukopová, J. (2017). Municipal Waste Strategy for Approaching European Union Recycling Targets. *In Cossu, R., Stegmann, R.. Proceedings Sardinia 2017, 16th International Waste Management and Landfill Symposium*. Sardinia, Italy: CISA Publisher, 1-24. ISBN 978-88-6265-010-6.

[88] Huang, Y., Pan, T. & Kao, J. (2011). Performance assessment for municipal solid waste collection in Taiwan. *Journal of Environmental Management*, 92(4), 1277-1283. https://doi.org/10.1016/j.jenvman.2010.12.002.

[89] ISOH (2018). *Informační Systém Odpadového Hospodářství*. https://isoh.mzp.cz.

[90] Jablonský, J. (2004). Modely hodnocení efektivnosti produkčních jednotek. *Politická ekonomie*, 52(2), 206-219. https://doi.org/10.18267/j.polek.458.

[91] Jablonský, J. (2002). *Operační výzkum: kvantitativní modely pro ekonomické rozhodování*. Praha: Professional Publishing, 322 p., ISBN 80-86419-42-8.

[92] Jablonský, J. & Dlouhý, M. (2015). *Modely hodnocení efektivnosti a alokace zdrojů*. Praha: Professional Publishing, 199 p. ISBN 978-80-7431-155-0.

[93] Jablonský, J. & Dlouhý, M. (2004). *Modely hodnocení efektivnosti produkčních jednotek*. Praha: Professional Publishing, 183 p. ISBN 978-80-86419-49-5.

[94] Jacobsen, R., Buysse, J. & Gellynck, X. (2013). Cost comparison between private and public collection of residual household waste: multiple case studies in the Flemish region of Belgium. *Waste Management*, 33(1), 3-11. https://doi.org/10.1016/j.wasman.2012.08.015.

[95] Jihomoravský kraj (2018). *Základní údaje o Jihomoravském kraji*. https://www.kr-jihomoravsky.cz/Default.aspx?ID=27204&TypeID=2.

[96] Johnstone, N. & Labonne, J. (2004). Generation of household solid waste in OECD countries: an empirical analysis using macroeconomic data. *Land Economics*, 80(4), 529-538. https://doi.org/10.2307/3655808.

[97] Kinnaman, T. C. & Fullerton, D. (1999). The economics of residential solid waste management. *NBER Working Paper No. 7326*. National bureau of economic research. https://doi.org/10.3386/w7326.

[98] Kirakozian, A. (2015). Household Waste Recycling: Economics and Policy. *GREDEG Working Paper Series, No. 2015-09*. https://ideas.repec.org/p/gre/wpaper/2015-09.html.

[99] Kirkpatrick, C., Parker, D. & Zhang, Y. (2006). State versus private sector provision of water services in Africa: An empirical Analysis, *The World bank economic review*, 20(1), 143-163. https://doi.org/10.1093/wber/lhj001.

[100] Knussen, C., Yule, F., MacKenzie, J. & Wells, M. (2004). An analysis of intentions to recycle household waste: The roles of past behaviour, perceived habit, and perceived lack of facilities. *Journal of Environmental Psychology*, 24(2), 237-246. https://dx.doi.org/10.1016/j.jenvp.2003.12.001.

[101] Knussen, C. & Yule, F. (2008). "I'm Not in the Habit of Recycling" The Role of Habitual Behavior in the Disposal of Household Waste. *Environment and Behavior*, 40(5), 683-702. https://dx.doi.org/10.1177/0013916507307527.

[102] Koopmans, T. C. (1951). An Analysis of Production as an Efficient Combination of Activities. *In Koopmans, T. C. (ed.) Activity Analysis of Production and Allocation*, Cowles Commission for Research in Economics. Monograph No. 13, New York: Wiley, 33-97.

[103] Korhonen, P. & Luptacik, M. (2004). Eco-efficiency analysis of power plants: An extension of data envelopment analysis, *European Journal of Operational Research*, 154(2), 437-446. https://doi.org/10.1016/S0377-2217(03)00180-2.

[104] Kumbhakar, S. C. & Lovell, C. A. K. (2000). *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press, 333 p. ISBN 0-521-66663-5. https://doi.org/10.1017/cbo9781139174411.

[105] Kuosmanen, T. & Kortelainen, M. (2005). Measuring Eco-efficiency of Production with Data Envelopment Analysis. *Journal of Industrial Ecology*, 9(4), 59-72. https://doi.org/10.1162/108819805775247846.

[106] Lebersorger, S. & Beigl, P. (2011). Municipal solid waste generation in municipalities: Quantifying impacts of household structure, commercial waste and domestic fuel. *Waste Management*, 31(9), 1907-1915. https://dx.doi.org/10.1016/j.wasman.2011.05.016.

[107] Linderhof, V., Kooreman, P., Allers, M. & Wiersma, D. (2001). Weight-based pricing in the collection of household waste: the Oostzaan case. *Resource and Energy Economics*, 23(4), 359-371. https://dx.doi.org/10.1016/S0928-7655(01)00044-6.

[108] Liu, J. S., Lu, L. Y., Lu, W. M. & Lin, B. J. (2013). Data envelopment analysis 1978–2010: A citation-based literature survey. *Omega*, 41(1), 3-15. https://doi.org/10.1016/j.omega.2010.12.006.

[109] Lovell, C. A. K. (2002). Performance Assessment in the Public Sector. *In Fox, K. J. (ed.) Efficiency in the Public Sector*. Norwell: Kluwer Academic Publishers, 11-35, ISBN 0-7923-7563-7. https://dx.doi.org/10.1007/978-1-4757-3592-5.

[110] Marques, R. C. & Simões, P. (2009). Incentive regulation and performance measurement of the Portuguese solid waste management services. *Waste Management & Research*, 27(2), 188-196. https://doi.org/10.1177/0734242X08095025.

[111] Martin, M., Williams, I. D. & Clark, M. (2006). Social, cultural and structural influences on household waste recycling: A case study. *Resources, Conservation and Recycling*, 48(4), 357-395. https://dx.doi.org/10.1016/j.resconrec.2005.09.005.

[112] Massarutto, A. (2007). Municipal waste management as a local utility: Options for competition in an environmentally-regulated industry. *Utilities Policy*, 15(1), 9-19. https://doi.org/10.1016/j.jup.2006.09.003.

[113] Mastromarco, C. (2008). Stochastic Frontier Models. *CIdE 2008*, Salento: University of Salento, Available at: http://www.camillamastromarco.it/CIDE/STFR.pdf.

[114] Mazzanti, M. & Zoboli, R. (2008). Waste generation, waste disposal and policy effectiveness: Evidence on decoupling from the European Union. *Resources, Conservation and Recycling*, 52(10), 1221-1234. https://dx.doi.org/10.1016/j.resconrec.2008.07.003.

[115] McCarty, J. A. & Shrum, L. J. (1994). The recycling of solid wastes: Personal values, value orientations, and attitudes about recycling as antecedents of recycling behavior. *Journal of Business Research*, 30(1), 53-62. https://dx.doi.org/10.1016/0148-2963(94)90068-X.

[116] Meadows, D. H., Meadows, D. L., Randers, J. & Behrens, W. W. (1972). *The limits to growth*. New York: Universe books, 205 p. ISBN 0-87663-165-0.

[117] Medveď, J., Nemec, J., Orviská, M. & Zimková, E. (2005). *Verejné financie*. Bratislava: Sprint, 464 p. ISBN 80-89085-32-6.

[118] Mee, N., Clewes, D., Phillips, P. S. & Read, A. D. (2004). Effective implementation of a marketing communications strategy for kerbside recycling: a case study from Rushcliffe, UK. *Resources, Conservation and Recycling*, 42(1), 1-26. https://dx.doi.org/10.1016/j.resconrec.2003.12.003.

[119] Meeusen, W. & Van den Broeck, J. (1977). Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review*, 18(2), 435-444. https://dx.doi.org/10.2307/2525757.

[120] Merickova, B. M., Nemec, J. & Soukopova, J. (2014). The Economics of Waste Management: Evidence from the Czech Republic and Slovakia. *Lex Localis*, 12(3), 431. https://doi.org/10.4335/12.3.431-449(2014).

[121] Mihaiu, D. M., Opreana, A. & Cristescu, M. P. (2010). Efficiency, effectiveness and performance of the public sector. *Romanian Journal of Economic Forecasting*, 13(4), 132-147. https://ideas.repec.org/a/rjr/romjef/vy2010i4p132-147.html.

[122] Mikušová Meričková, B., Nemec, J. & Vozárová, Z. (2017). The Efficiency of Contracting Out Local Public Services in the Czech Republic and Slovakia. *In Douglas J. Besharov, Karen J. Beahler, Jacob Alex Klerman. Improving Public Services*. New York: Oxford University Press. 265-285, ISBN 978-0-19-064605-9. https://doi.org/10.1093/acprof:oso/9780190646059.003.0012.

[123] Miliute-Plepiene, J., Hage, O., Plepys, A. & Reipas, A. (2016). What motivates households recycling behaviour in recycling schemes of different maturity? Lessons from Lithuania and Sweden. *Resources, Conservation and Recycling*, 113, 40-52. https://dx.doi.org/10.1016/j.resconrec.2016.05.008.

[124] Mintzberg, H. (1996). Managing Government, Government Managed. *Harvard Business Review*, 74(3), 75-83.

[125] Moore, A., Nolan, J. & Segal, G. F. (2005). Putting out the trash: Measuring municipal service efficiency in US cities. *Urban Affairs Review*, 41(2), 237-259. https://doi.org/10.1177/1078087405279466.

[126] MONITOR (2018). *Information portal of the Ministry of Finance of the Czech Republic*. http://monitor.statnipokladna.cz/.

[127] Musgrave, R. A. & Musgrave, P. B. (1984). *Public finance in theory and practice*. New York: McGraw-Hill, 824 p., ISBN 0-07-044126-X.

[128] MŽP (2017a). Environmental Protection in the Czech Republic: Experience and Know-How. https://www.mzp.cz/web/edice.nsf/da28f37425da72f7c12569e600723950/4b90fd93a463b9f7c12581bd002d701d.

[129] MŽP (2017b). Souhrnná data o odpadovém hospodářství ČR v letech 2009 – 2016. https://www.mzp.cz/C1257458002F0DC7/cz/odpadove_hospodarstvi_data_2015/$FILE/OODP-Souhrnna_data_2009_2016-20171006.pdf.

[130] MŽP (2017c). Statistická ročenka životního prostředí České republiky 2016. https://www.mzp.cz/cz/statisticka_rocenka_zivotniho_prostredi_publikace.

[131] MŽP (2017d). Zpráva o životním prostředí České republiky v roce 2016. https://www.mzp.cz/cz/zpravy_o_stavu_zivotniho_prostredi_publikace.

[132] Nemec, J., Meričková, B. & Šumpíková, M. (2007). Contracting out at local government level in Slovakia and the Czech Republic. *E+ M Economics and Management*, 10(3), 5-13.

[133] Nemec, J., Merickova, B. & Vitek, L. (2005). Contracting-out at local government level: theory and selected evidence from the Czech and Slovak Republics. *Public Management Review*, *7*(4), 637-647. https://doi.org/10.1080/14719030500362900.

[134] Nemec, J., Ochrana, F., Pavel, J. & Šagát, V. (2010). *Kontrola ve veřejné správě*. Praha: Wolters Kluwer ČR, 160 p., ISBN 978-80-7357-558-8.

[135] Ochrana, F. (2011). *Veřejné výdajové programy, veřejné projekty a zakázky*. Praha: Wolters Kluwer ČR, 220 p., ISBN 978-80-7357-644-8.

[136] Ochrana, F. (2006). *Programové financování a hodnocení veřejných výdajů : teorie a metodika hodnocení veřejných výdajů a veřejných služeb v systému programové alokace zdrojů*. Praha: Ekopress, 189 p., ISBN 80-86929-13-2.

[137] Ochrana, F. (2005). *Nákladově užitkové metody ve veřejném sektoru*. Praha: Ekopress, 175 p., ISBN 80-86119-96-3.

[138] Ochrana, F. (2001). *Veřejný sektor a efektivní rozhodování*. Praha: Management Press, 246 p. ISBN 80-7261-018-X.

[139] Ochrana, F., Fantová Šumpíková, M., Pavel, J., Nemec, J. et al. (2007). *Efektivnost zabezpečování vybraných veřejných služeb na úrovni obcí*. Praha: Nakladatelství Oeconomica, 152 p., ISBN 978-80-245-1259-4.

[140] Ohlsson, H. (2003). Ownership and production costs: choosing between public and private production and contracting-out in the case of Swedish refuse collection. *Fiscal Studies*, 24(4), 451–476. https://doi.org/10.1111/j.1475-5890.2003.tb00091.x.

[141] Oskamp, S., Harrington, M. J., Edwards, T. C., Sherwood, D. L., Okuda, S. M. & Swanson, D. C. (1991). Factors influencing household recycling behavior. *Environment and Behavior*, 23(4), 494-519. https://dx.doi.org/10.1177/0013916591234005.

[142] Passarini, F., Vassura, I., Monti, F., Morselli, L. & Villani, B. (2011). Indicators of waste management efficiency related to different territorial conditions. *Waste management*, 31(4), 785-792. https://doi.org/10.1016/j.wasman.2010.11.021.

[143] Perrin, D. & Barton, J. (2001). Issues associated with transforming household attitudes and opinions into materials recovery: a review of two kerbside recycling schemes. *Resources, Conservation and Recycling*, 33(1), 61-74. https://dx.doi.org/10.1016/S0921-3449(01)00075-1.

[144] Pickerin, P. L. & Shaw, P. J. (2015). Age and ageing as factors influencing waste management behaviour. *In R. Cossu, P. He, P. Kjeldsen, Y. Matsufuji, D. Reinhart, R. Stegman (eds.) SARDINIA 2015 – 15th International Waste Management and Landfill Symposium Proceedings*, Padova, CISA. ISBN 9788862650212.

[145] Porcelli, F. (2009). *Measurement of Technical Efficiency – A brief survey on parametric and non-parametric techniques*, University of Warwick. www2.warwick.ac.uk/ fac/soc/economics/staff/phd_students/porcelli/porcelli_dea_sfm.pdf.

[146] Põldnurk, J. (2015). Optimisation of the economic, environmental and administrative efficiency of the municipal waste management model in rural areas. *Resources, Conservation and Recycling*, 97, 55-65. https://doi.org/10.1016/j.resconrec.2015.02.003.

[147] Ramanathan, R. (2003). *An Introduction to Data Envelopment Analysis: A tool for performance measurement*. New Delhi: Sage Publications India, 201 p. ISBN 0-7619-9760-1.

[148] Ray, S. C. (2004). *Data envelopment analysis: theory and techniques for economics and operations research*, Cambridge University Press, 353 p. ISBN 0-521-80256-3.

[149] Ray, S. C. (1988). Data envelopment analysis, nondiscretionary inputs and efficiency: an alternative interpretation. *Socio-Economic Planning Sciences*, 22(4), 167-176. https://doi.org/10.1016/0038-0121(88)90003-1.

[150] Reeves, E. & Barrow, M. (2000). The impact of contracting-out on the costs of refuse collection services. The case of Ireland. *The Economic and Social Review*, 31(2), 129–150. https://ideas.repec.org/a/eso/journl/v31y2000i2p129-150.html.

[151] Richmond, J. (1974). Estimating the Efficiency of Production. *International Economic Review*, 15(2), 515-521. https://doi.org/10.2307/2525875.

[152] Rogge, N. & De Jaeger, S. (2012). Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model. *Waste Management*, 32(10), 1968-1978. https://doi.org/10.1016/j.wasman.2012.05.021.

[153] Rogge, N. & De Jaeger, S. (2013). Measuring and explaining the cost efficiency of municipal solid waste collection and processing services. *Omega*, 41(4), 653-664. https://doi.org/10.1016/j.omega.2012.09.006.

[154] Russell, R. R. (1998). Distance Functions in Consumer and Producer Theory. *In Färe, R. et al. (eds.) Index Numbers: Essays In Honour of Sten Malmquist*. Springer Netherlands, 7-90. ISBN 978-94-010-6035-6. https://doi.org/10.1007/978-94-011-4858-0_2.

[155] Saphores, J. D. M. & Nixon, H. (2014). How effective are current household recycling policies? Results from a national survey of US households. *Resources, Conservation and Recycling*, 92, 1-10. https://dx.doi.org/10.1016/j.resconrec.2014.08.010.

[156] Schultz, P. W., Oskamp, S. & Mainieri, T. (1995). Who recycles and when? A review of personal and situational factors. *Journal of Environmental Psychology*, 15(2), 105-121. https://dx.doi.org/10.1016/0272-4944(95)90019-5.

[157] Seiford, L. M. (2005). *A Cyber-Bibliography for Data Envelopment Analysis (1978-2005)*. Available at http://en.convdocs.org/docs/index-8834.html.

[158] Shaw, P. J. (2008). Nearest neighbour effects in kerbside household waste recycling. *Resources, Conservation and Recycling*, 52(5), 775-784. https://dx.doi.org/10.1016/j.resconrec.2007.11.004.

[159] Shaw, P. J. & Maynard, S. J. (2008). The potential of financial incentives to enhance householders' kerbside recycling behaviour. *Waste Management*, 28(10), 1732-1741. https://dx.doi.org/10.1016/j.wasman.2007.08.008.

[160] Sidique, S. F., Joshi, S. V. & Lupi, F. (2010). Factors influencing the rate of recycling: An analysis of Minnesota counties. *Resources, Conservation and Recycling*, 54(4), 242-249. https://dx.doi.org/10.1016/j.resconrec.2009.08.006.

[161] Simar, L. & Wilson, P. W. (2011). Two-stage DEA: caveat emptor. *Journal of Productivity Analysis*, 36(2), 205-218. https://doi.org/10.1007/s11123-011-0230-6.

[162] Simões, P., Cruz, N. F. & Marques, R. C. (2012). The performance of private partners in the waste sector. *Journal of Cleaner Production*, 29, 214-221. https://doi.org/10.1016/j.jclepro.2012.01.027.

[163] Simões, P., De Witte, K., & Marques, R. C. (2010). Regulatory structures and operational environment in the Portuguese waste sector. *Waste management*, 30(6), 1130-1137. https://doi.org/10.1016/j.wasman.2009.12.015.

[164] Simões, P. & Marques, R. C. (2012). On the economic performance of the waste sector. A literature review. *Journal of Environmental Management*, 106, 40-47. https://doi.org/10.1016/j.jenvman.2012.04.005.

[165] Sivák, R. et al. (2007). *Verejné financie*. Bratislava: Iura Edition, 301 p. ISBN 978-80-8078-094-4.

[166] Slavík, J. & Pavel, J. (2013). Do the variable charges really increase the effectiveness and economy of waste management? A case study of the Czech Republic. *Resources, Conservation and Recycling*, 70, 68-77. https://dx.doi.org/10.1016/j.resconrec.2012.09.013.

[167] Soukopová, J., Hřebíček, J. & Valta, J. (2015). National Environmental Data Facilities and Services of the Czech Republic and Their Use in Environmental Economics. *In Denzer R., Argent R.M., Schimak G., Hřebíček J. (eds.) Environmental Software Systems. Infrastructures, Services and Applications. ISESS 2015. IFIP Advances in*

Information and Communication Technology, vol. 448, 361-370. https://doi.org/10.1007/978-3-319-15994-2_36.

[168] Soukopová, J. & Kalina, J. (2012). Mathematical model of economics of municipal waste management. *In Jaroslav Ramík and Daniel Stavárek. Proceedings of the 30th International Conference Mathematical Methods in Economics 2012*, Karviná: Silesian University in Opava, School of Business Administration in Karviná, 823-829. ISBN 978-80-7248-779-0.

[169] Soukopová, J., Malý, I., Hřebíček, J. & Struk, M. (2013). Decision Support of Waste Management Expenditures Efficiency Assessment. *In Hřebíček J., Schimak G., Kubásek M., Rizzoli A.E. (eds.) Environmental Software Systems. Fostering Information Sharing. ISESS 2013. IFIP Advances in Information and Communication Technology*, vol. 413, 651-660. https://doi.org/10.1007/978-3-642-41151-9_61.

[170] Soukopová, J., Nemec, J., Matějová, L. & Struk, M. (2014). Municipality Size and Local Public Services: Do Economies of Scale Exist? *NISPAcee Journal of Public Administration and Policy*, 7(2), 151-171. https://doi.org/10.2478/nispa-2014-0007.

[171] Soukopová, J., Struk, M. & Hřebíček, J. (2017). Population Age Structure and the Cost of Municipal Waste Collection. A case study from the Czech Republic. *Journal of Environmental Management*, 203(P2), 655-663. https://dx.doi.org/10.1016/j.jenvman.2016.03.030.

[172] Sterner, T. & Bartelings, H. (1999). Household waste management in a Swedish municipality: determinants of waste disposal, recycling and composting. *Environmental and Resource Economics*, 13(4), 473-491. https://doi.org/10.1023/A:1008214417099.

[173] Strecková, Yvonne a kol. (2005). *Faktory efektivnosti fungování veřejného sektoru a obecné poznatky o vlivu řízení veřejného sektoru na rozvoj region*. Brno: Masarykova univerzita, 243 p. ISBN 80-210-3623-0.

[174] Struk, M. (2017a). Distance and incentives matter: The separation of recyclable municipal waste. *Resources, Conservation and Recycling*, 122, 155-162. https://dx.doi.org/10.1016/j.resconrec.2017.01.023.

[175] Struk, M. (2017b). The Effect of Waste Management Company Change on Municipal Solid Waste Expenditures. *In Cossu, R., Stegmann, R. (eds.) Proceedings Sardinia*

2017, 16th International Waste Management and Landfill Symposium. Sardinia, Italy: CISA Publisher, 1-10. ISBN 978-88-6265-010-6.

[176] Struk, M. (2015a). Efficiency factors in municipal solid waste management. *In Raffaello Cossu, Pinjing He, Peter Kjeldsen, Yasushi Matsufuji, Debra Reinhart, Rainer Stegman (eds.) SARDINIA 2015 - 15th International Waste Management and Landfill Symposium - Symposium Proceedings*. Padova, Italy: CISA, 2015, 1-13. ISBN 978-88-6265-021-2.

[177] Struk, M. (2015b). Estimating municipal solid waste expenditures – the case of South Moravian Region. *In Dagmar Špalková, Lenka Matějová (eds.) Proceedings of the 19th International Conference Current Trends in Public Sector Research*. Brno: Masarykova univerzita, 324-331. ISBN 978-80-210-7532-0.

[178] Struk, M. & Matulová, M. (2016). The Application Of Two-Stage Data Envelopment Analysis On Municipal Solid Waste Management In The Czech Republic. *In Marián Reiff, Pavel Gežík. Quantitative Methods in Economics; Multiple Criteria Decision Making XVIII*. Bratislava: University of Economics, 349-355. ISBN 978-80-972328-0-1.

[179] Struk, M. & Soukopová, J. (2016). Age Structure and Municipal Waste Generation and Recycling – New Challenge for the Circular Economy. *In 4th International Conference on Sustainable Solid Waste Management*, 23rd - 25th June 2016 Limassol, Cyprus.

[180] Stuart-Hamilton, I. (1999). *Key ideas in psychology*. Jessica Kingsley Publishers, 336 p. ISBN: 978-1-84642-702-2

[181] Sturrock (1957). Discussion on Mr. Farrell's Paper. *Journal of Royal Statistical Society*, Series A, General, 120, Part 3, 285-285. https://dx.doi.org/10.2307/2343100.

[182] Szymanski S. (1996). The impact of compulsory competitive tendering on refuse collection services. *Fiscal studies*, 17(3), 1-19. https://doi.org/10.1111/j.1475-5890.1996.tb00491.x.

[183] Szymanski, S. & Wilkins, S. (1993). Cheap rubbish? Competitive tendering and contracting out in refuse collection–1981–88. *Fiscal studies*, 14(3), 109-130. https://doi.org/10.1111/j.1475-5890.1993.tb00489.x.

[184] Šauer, P., Pařízková, L. & Hadrabová, A. (2008). Charging systems for municipal solid waste: Experience from the Czech Republic. *Waste Management*, 28(12), 2772-2777. https://dx.doi.org/10.1016/j.wasman.2008.03.030.

[185] Šumpíková, M., Ochrana, F., Pavel, J. a kol. (2005). *Veřejné výdajové program a jejich efektivnost*. Praha: Eurolex Bohemia, 230 p., ISBN 80-86861-77-5.

[186] Talalaj, I. A. & Walery, M. (2015). The effect of gender and age structure on municipal waste generation in Poland. *Waste Management*, 40, 3-8. https://dx.doi.org/10.1016/j.wasman.2015.03.020.

[187] Thanassoulis, E., Portela, M. C. S. & Despić, O. (2008). Data Envelopment Analysis: The Mathemetical Programming Approach to Efficiency Analysis. *In Fried, H. O. et al. (eds.) The Measurement of Productive Efficiency and Productivity Growth*. Oxford University Press, 251-420, ISBN 978-0-19-518352-8. http://dx.doi.org/10.1093/acprof:oso/9780195183528.001.0001.

[188] Thøgersen, J. (2003). Monetary incentives and recycling: Behavioural and psychological reactions to a performance-dependent garbage fee. *Journal of Consumer Policy*. 26(2), 197-228. https://dx.doi.org/10.1023/A:1023633320485.

[189] Vishwakarma, A., Kulshrestha, M. & Kulshreshtha, M. (2012). Efficiency evaluation of municipal solid waste management utilities in the urban cities of the state of Madhya Pradesh, India, using stochastic frontier analysis. *Benchmarking: An International Journal*, 19(3), 340-357. https://doi.org/10.1108/14635771211242996.

[190] Vlček, J. (1992). *Výkladový lexikon pojmů tržní ekonomiky*. Praha: Victoria Publishing, 215 p., ISBN 80-85605-26-0.

[191] Vohralíková, L. & Rabušic, L. (2004). *Čeští senioři včera, dnes a zítra*. VÚPSV, Výzkumné centrum Brno. 90 p. http://praha.vupsv.cz/Fulltext/vz_149.pdf.

[192] Williams, I. D. & Taylor, C. (2004). Maximising household waste recycling at civic amenity sites in Lancashire, England. *Waste Management*, 24(9), 861-874. https://dx.doi.org/10.1016/j.wasman.2004.02.002.

[193] Wilson, D. C., Velis, C. & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. *Habitat international*, 30(4), 797-808. https://doi.org/10.1016/j.habitatint.2005.09.005.

[194] Wilson, C. D. H. & Williams, I. D. (2007). Kerbside collection: A case study from the north-west of England. *Resources, Conservation and Recycling*, 52(2), 381-394. https://dx.doi.org/10.1016/j.resconrec.2007.02.006.

[195] Woodbury, K. & Dollery, B. (2004). Efficiency Measurement in Australian Local Government: The Case of New South Wales Municipal Water Services, *Review of Policy Research*, 21(5), 615-636. https://doi.org/10.1111/j.1541-1338.2004.00098.x.

[196] Worthington, A. C. (2014). A review of frontier approaches to efficiency and productivity measurement in urban water utilities. *Urban Water Journal*, 11(1), 55-73. https://doi.org/10.1080/1573062X.2013.765488.

[197] Worthington, A. C. & Dollery, B. E. (2001). Measuring efficiency in local government: An analysis of New South Wales municipalities' domestic waste management function. *Policy Studies Journal*, 29(2), 232-249. https://doi.org/10.1111/j.1541-0072.2001.tb02088.x.

[198] Závodská, A., Benešová, L., Smyth, B. & Morrissey, A. J. (2014). A comparison of biodegradable municipal waste (BMW) management strategies in Ireland and the Czech Republic and the lessons learned. *Resources, Conservation and Recycling*, 92, 136-144. https://dx.doi.org/10.1016/j.resconrec.2014.09.007.

[199] Zheng, P., Zhang, K., Zhang, S., Wang, R. & Wang, H. (2017). The door-to-door recycling scheme of household solid wastes in urban areas: a case study from Nagoya, Japan. *Journal of Cleaner Production*, 163, S366-S373. https://dx.doi.org/10.1016/j.jclepro.2016.03.106.

SUMMARY, LIST OF FIGURES, TABLES AND ABBREVIATIONS

Summary

Provided thesis examines selected efficiency factors related to municipal waste management, Objectives in this thesis are to 1) describe situation in municipal solid waste management in a selected Czech region; and 2) identify relevant efficiency factors in this region using both collected data and available literature, and based on further analysis provide policy suggestions for improving municipal waste management in the region. After the initial definition of the efficiency in the public sector, the target area of municipal waste management in the Czech Republic was introduced. Relevant methods for measuring efficiency were described and an overview of literature dealing with the issue was presented. This overview resulted in an identification of the most common efficiency factors related to municipal solid waste management. In addition to that, own collection of primary data from a sample of more than 500 municipalities in South Moravian Region was performed, in order to identify other potential efficiency factors relevant to municipal waste management. These primary data were accompanied by available secondary data from public databases. Collected data was then used in a quantitative analysis employing Two-stage Data Envelopment Analysis, what provided additional efficiency factors that were considered as relevant with respect to the municipal solid waste management. Based on literature overview and quantitative analysis of the primary and secondary data, specific efficiency factors were selected for the further detailed analysis. These included separation convenience factors (availability of kerbside collection, density of drop-off sites), presence of incentives related to the waste management, ages structure of the municipality, level of competition present in the waste management provision and the nature of the waste management company ownership. Analyses of these factors showed that both convenience and incentives play an important role in the waste management and can lead to substantial improvement in both economic and environmental terms. Age structure of a municipality is also an important factor to consider, as various age cohorts can have notably different effect on waste generation and expenditure. Proper utilization of these finding has a lot of potential in improving the overall performance of municipal waste management. Finally, results also showed that not the ownership nature of the waste company is important, but instead the sufficient level of competition among them.

Figures

Figure 1: Scheme of determining the specific efficiency indicator 22
Figure 2: Capital (investment) and current (non-investment) EPE in the Czech Republic, 2003-2015 29
Figure 3: Total waste generation in the Czech Republic, million tons, 2009-2016 31
Figure 4: Waste generation in the Czech Republic in 2016 by categories 32
Figure 5: Municipal waste generation in the Czech Republic, million tons, 2009-2016 34
Figure 6: Municipal waste treatment in the Czech Republic, million tons, 2010-2016 36
Figure 7: Histogram of Czech municipal solid waste expenditure per capita, 2016 39
Figure 8: Development of municipal environmental protection expenditure by categories, 2009-16 40
Figure 9: Development of municipal waste management expenditure by categories, 2009-16 41
Figure 10: Example of CRS and VRS efficiency frontier, case with 7 DMUs, 1 output, 1 input 92
Figure 11: Frequency distribution of calculated efficiency scores of municipalities 101
Figure 12: Frequency distribution of municipality population size of the sample, 2012 state 114
Figure 13: Average and median paper and plastics separation rates 118
Figure 14: Average amount of generated waste per capita according to the municipality size 121
Figure 15: Municipal solid waste expenditure per capita for 2011 and 2014 139
Figure 16: Interannual change in MSWE after the change of the WM company (66 municipalities), standard errors for averages included 152
Figure 17: Relative changes in MSWE of individual municipalities after the change of WM company (66 municipalities) 153
Figure 18: Comparison of MSWE before and two years after the change of the waste management company (52 municipalities), standard errors for averages included 154
Figure 19: MSWE change according to the company ownership change (62 municipalities) 156

Tables

Table 1: Main differences between public and private organizations 20
Table 2: Overview of 3E criteria 20
Table 3: Basic data about South Moravian Region, 2017 56
Table 4: Basic descriptive statistics about interviewed sample of municipalities, 2011 79
Table 5: Descriptive statistics of the analyzed sample of 463 municipalities by quartiles 88
Table 6: Published DEA-related papers indexed in Web of Science and Scopus, 2004-17 91
Table 7: List of DEA solving programs 95
Table 8: Effects of selected MSWM characteristics on MSWM efficiency 102
Table 9: Descriptive statistics of the municipalities in the sample 115
Table 10: Estimated effects of collection systems and incentives on separation rates (in %) 119
Table 11: Average amount of generated waste per capita with and without incentive program 120
Table 12: People in the main age categories in the Czech Republic, 2011 and 2014 132
Table 13: Reduction of the amount of municipalities in the subsamples 135
Table 14: OLS estimation, Czech municipalities, 0.5% trimmed sample 136

Table 15: Residual MSW generation per capita for the individual age groups 141
Table 16: Separated municipal waste generation per capita for the individual age groups 144
Table 17: Description of the sample of municipalities (with respect to the year of the change) 151
Table 18: Year of the waste management company change, 66 municipalities 151
Table 19: Waste management company ownership before/after the change, 66 municipalities 151

Abbreviations

2SDEA – Two-Stage Data Envelopment Analysis

3E – economical concept including Economy, Efficiency and Effectiveness

CEA – Cost-effectiveness Analysis

CENIA – Czech Environmental Information Agency

CUA – Cost-utility Analysis

CZK – Czech koruna (currency), also known as Kč

CZSO – Czech Statistical Office

DEA – Data Envelopment Analysis

DMU – decision making unit

EPE – environmental protection expenditure

GDP – gross domestic product

HWRC – household waste recycling center, also known as civic amenity (CA) site

MF ČR – Ministry of Finance of the Czech Republic

MSW – municipal solid waste

MSWE – municipal solid waste expenditure

MSWM – municipal solid waste management

MŽP – Ministry of the Environment of the Czech Republic

OLS – Ordinary least squares

PAYT – Pay-as-you-throw

SFA – Stochastic Frontier Analysis

WEEE – waste electrical and electronic equipment

WM – waste management